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Making local knowledge matter: Exploring the appropriateness of pictorial decision trees as interaction style for non-literate communities to capture their traditional ecological knowledge

Michalis Vitos

A thesis submitted for the Degree of Doctor of Philosophy (PhD)

May 2018

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Department of Civil, Environmental, and Geomatic Engineering
ExCiteS Research Group

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Declaration

I, **Michalis Vitos** have read and understood the College and Department's statements and guidelines concerning plagiarism.

I confirm that the work presented in this thesis is my own. Where information has been derived from other sources, I confirm that this has been indicated in the thesis.

London,
May 2018

Abstract

Sustainable natural resource management is one of the fundamental development challenges humanity faces today. The scale of the issues involved and the inadequacy of existing paradigms mean that there is an urgent need for innovative and appropriate solutions to enable scientifically-informed sustainable resource management of key environments. Local and indigenous communities often possess unique Traditional Ecological Knowledge (TEK) about their natural resources, which despite being increasingly recognised as critical for sustaining and protecting the environment, it is difficult to capture in a digital format, in particular given the environment in which many communities live and their lack of technical knowledge. Yet, their knowledge is required in digital form to reach a wide audience and particularly those stakeholders who need to base their decisions on the knowledge provided.

This thesis draws knowledge from Human-Computer Interaction (HCI), HCI for Development (HCI4D), Software Engineering, Information and Communications Technologies for Development (ICT4D), Participatory Geographic Information Systems (PGIS) and Citizen Science to develop and evaluate methods and Information and Communications Technology (ICT) tools to enable communities to capture and share their local environmental conditions, information that can in turn lead to improvements in environmental governance and social-environmental justice.

One core challenge in this endeavour is to enable lay users, especially those with limited technical skills or no prior exposure to technology and no (or basic) literacy or no formal education, to use smartphones to capture their TEK and share data with relevant stakeholders. To achieve that, this thesis explores whether pictorial decision trees are appropriate as an interaction mode for non-literate participants to capture geographical data. In the context of three case studies, taking place in Republic of the Congo and focusing on enabling local communities to participate in socio-environmental monitoring schemes regarding their forest, this thesis explores the opportunities and challenges in collaboratively developing software to realise this vision.

The research findings and the methodological framework provide an approach and guidelines for the development and evaluation of ICT solutions in similar, challenging environments. The most significant finding of the thesis is that while pictographs are easily understood by participants, when employed in pictorial decision trees they proved to be challenging for them due to the categorisation and hierarchical structure of decision trees. Alternatively, interaction modes that employ audio or physical interfaces can alleviate these issues and assist participants to collect geographical data. This thesis also demonstrates how a participatory and iterative design approach led to the conception and evaluation of interaction modes that increase participants' accuracy from 75% towards 95% and improve participants' satisfaction, which could in turn increase the sustainability of the project. Finally, a number of methodological approaches were evaluated and amended in order to design and evaluate ICT solutions with non-literate, forest communities.

Impact statement

The research undertaken in the present thesis attempted to contribute in the resolution of sustainable development – one of the most significant, worldwide and pressing issues, as identified by United Nations (UN) in their Millennium Development Goals (MDGs) and Sustainable Development Goals (SDGs). Recently there is a growing imperative to record and protect TEK, as it is recognised as a promising solution to achieve long-term and sustainable management of ecosystems. Local and indigenous communities around the world, possess a rare and complex understanding of their territory and the wider vision for this research was to provide the technological means to support them to share and apply their TEK and their knowledge of local environmental conditions using scientifically accepted methods that could lead to improvements in environmental governance and social-environmental justice.

In the wider area of sustainability and data collection of TEK, this thesis narrowed the research focus on the usability of the suggested ICT tools to gather TEK. As a result it contributes to the rich literature of ICT4D and HCI for Development (HCI4D), by exploring whether pictorial decision trees are appropriate as an interaction mode for non-literate participants to capture and share their TEK. In addition, this thesis contributes by providing a methodological approach for evaluating ICT tools among remote communities and stakeholders. This thesis has presented research work with marginalised groups, such as indigenous forest communities in the Republic of the Congo, and it has demonstrated that following an interdisciplinary approach, and adapting methods from User-Centred Design (UCD), **it is feasible** to enable participants to use scientifically acceptable methods to collect local environmental data and participate in decision-making processes.

As noted, the main focus of this thesis was the usability evaluation and improvement of the tools that could positively impact the sustainability of the approach. As a result, this thesis provides methods for conducting evaluation studies '*in the wild*'. Through three case studies, it has presented the key elements of a methodological approach for introducing and evaluating the technology against local communities, who have often received little or no formal education or exposure to technology. As a result, it has provided an in-depth look at the methodology for conducting usability evaluations outside of the controlled and 'safe' environment of the lab, that resulted in an accuracy improvement of the tools from 75% to over 95%. Thus, it provides project design and engagement guidelines for similar, challenging environments.

Finally, the novelty of the work described in the present thesis lies in the conception, development and testing of the interaction modes for data collection, which permit an entire community, regardless of skills or literacy levels, to create maps of essential features of their local environment for use in logging consultations and improve collaboration and communication. In terms of user interaction, this research is proposing three different interfaces to enable local people to participate in data collection schemes and monitoring activities. It suggests pictorial decision trees as an effective method for semi-literate participants, without and with audio feedback for enhancing the user experience. Finally, it proposes physical interfaces for users with minimal or no formal education for building their confidence and performance.

Although the methodologies and the tools presented here are still work in progress, they could provide a concrete base for long-term engagement and successful development outcomes. Apart from the Republic of the Congo, the same methodologies are used with communities in the Brazilian Amazon to develop land management tools, while in Namibia these ICT tools will be used by Ju 'hoansi communities to monitor and report illegal invasions of their lands by cattle ranchers.

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> *No matter what accomplishments you make, somebody helped you.*
>
> — **Althea Gibson (1927 – 2003)**
> Golfer, Tennis Player, Athlete

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Contents

List of Figures xix

List of Tables xxiii

List of Listings xxv

List of Acronyms xxvii

1 Introduction 1
- 1.1 Related Work 2
- 1.2 Research Aims and Objectives 6
- 1.3 Research Overview 6
- 1.4 Contribution 8
- 1.5 Writing Conventions and Terminology 9
- 1.6 Outline 10

2 Motivation 15
- 2.1 Millennium Development Goals 16
- 2.2 Human Development 17
- 2.3 Sustainable Development 17
- 2.4 International Development 18
- 2.5 Appropriate Technology 19
- 2.6 Participatory Learning and Action 20
- 2.7 Traditional Ecological Knowledge 21
- 2.8 ICT4D 22
- 2.9 Citizen Science 23
- 2.10 Summary 24

3 Research Context 27
- 3.1 Social context 28
  - 3.1.1 Indigenous people 28
  - 3.1.2 Settled communities 31
  - 3.1.3 Local issues 32
- 3.2 Technological and social challenges 33

3.2.1 Literacy 36
3.2.2 Language 36
3.2.3 Technological challenges 38
3.2.4 Security issues 39
3.2.5 Summary 39

4 Related Work 41
4.1 ICT4D 42
4.1.1 ICT for illiterate and non-literate users 43
4.1.2 ICT4D for geographical data collection 47
4.2 Human-Computer Interaction (HCI) 51
4.2.1 HCI Goals and Usability Principles 52
4.2.2 Interaction Design 54
4.2.3 HCI4D 56
4.2.4 HCI research ‘in the wild’ 57
4.3 ICT4D vs HCI4D 57
4.4 Audio and physical interfaces 58
4.5 Research Gap 60
4.6 Summary 61

5 Overall Methodology 63
5.1 Research questions 63
5.2 Methodological approach 65
5.2.1 Action Research 67
5.2.2 User-Centred Design 71
5.2.3 Usability Engineering 75
5.2.4 Methodologies in this thesis 80
5.3 Case studies 83
5.3.1 Case study 1: Participatory monitoring of poaching 86
5.3.2 Case study 2: Participatory monitoring of logging 87
5.3.3 Case study 3: Participatory monitoring of logging 88
5.3.4 Project and Research contributions 89
5.3.5 Ethical considerations 93
5.4 Summary 94

6 Case study 1: Participatory monitoring of poaching 97
6.1 Helping communities to fight poaching 98
6.2 Requirements Analysis 100
6.3 Hardware and software evaluation 102
6.4 Prototype development 103
6.4.1 Decision tree 107
6.4.2 Navigation 107
6.5 Evaluation 109

6.5.1 Cognitive Walkthrough . . . 109
6.5.2 Field evaluation . . . 111
6.5.3 Results . . . 112
6.6 Discussion . . . 114
6.6.1 RQ 2 . . . 115
6.6.2 RQ 1 . . . 116
6.7 Summary . . . 118

7 Case study 2: Participatory monitoring of logging 119
7.1 Social context . . . 120
7.2 Participatory monitoring of logging . . . 122
7.3 Requirements Analysis . . . 123
7.4 Prototype development . . . 124
7.4.1 Sapelli Collector . . . 125
7.4.2 Sapelli Launcher . . . 128
7.5 Evaluation . . . 129
7.5.1 Cognitive Walkthrough . . . 130
7.5.2 Field evaluation . . . 132
7.5.3 Results . . . 136
7.6 Discussion . . . 141
7.6.1 RQ 2 . . . 141
7.6.2 RQ 1 . . . 143
7.7 Summary . . . 144

8 Case study 3: Participatory monitoring of logging 145
8.1 Social context . . . 146
8.2 Requirements analysis . . . 147
8.3 Prototype development . . . 147
8.3.1 Audio Feedback . . . 149
8.3.2 Log user interactions . . . 152
8.4 Evaluation . . . 153
8.4.1 Audio feedback . . . 157
8.4.2 Tap&Map: Exploring physical interfaces . . . 163
8.5 Discussion . . . 169
8.6 RQ 2 . . . 169
8.7 RQ 1 . . . 171
8.8 Summary . . . 173

9 Discussion 175
9.1 Restating the research questions . . . 175
9.2 RQ 1 . . . 178
9.3 RQ 2 . . . 187
9.4 Strengths and Limitations . . . 193

9.5 Implications and Contributions 198
9.6 Summary 200

10 Summary and Future Work 203
10.1 Research Overview 203
10.1.1 Case study 1: Participatory monitoring of poaching 204
10.1.2 Case study 2: Participatory monitoring of logging 205
10.1.3 Case study 3: Participatory monitoring of logging 206
10.2 Conclusions 207
10.3 Future work 208
10.3.1 Data collection 208
10.3.2 Ethical considerations 211
10.3.3 Moving beyond data collection 212
10.4 Closing remarks 212

A Commercial Evaluation 213
A.1 Executive Summary 215
A.2 Elevator Pitch 217
A.3 Company Summary 217
A.4 Services 220
A.5 The Market 225
A.6 Strategy and Implementation 228
A.7 Management Summary 234
A.8 Financial Plan 234
Appendix I: CV 238

B Case study 1: Participatory monitoring of poaching: Technical work 241
B.1 Requirements 241
B.2 Hardware Evaluation 246
B.3 Software Evaluation 249
B.4 Software Development 255
B.5 New requirements 259

C Review of data collection platforms 261
C.1 Platforms 261
C.2 Evaluation 267
C.3 Conclusion 274

D Anti-Poaching XForms 277

E Anti-Poaching Decision Tree 303

F Case study 2: Participatory monitoring of logging: Technical work 307
F.1 Requirements 307

F.2 Limitations of ODK-based prototype 312
F.3 Sapelli Development 315
F.4 New requirements 332

G XForms vs Sapelli XML **335**

H IM-FLEG Decision Tree **343**

I Case study 3: Participatory monitoring of logging: Technical work **349**
I.1 Requirements 349
I.2 Sapelli development 350

Bibliography **355**

List of Figures

3.1 Map of major Pygmy groups. *Adapted from Bahuchet (2006). Base layer © Google Earth Pro.* . . . 29
3.2 International literacy rates for adults. *Data from UNESCO Institute for Statistics (UIS, 2013).* . . . 37

4.1 CyberTracker's User Interface. *Source: Cybertracker (2015).* . . . 48
4.2 Examples of the hand-held Personal Digital Assistant (PDA) system. © *Jerome Lewis, ExCiteS group* . . . 50
4.3 Example of a simple decision tree about transport modes. . . . 50

5.1 Cycle of planning, acting, observing and reflecting. *Adapted from Zuber-Skenitt (1993).* . . . 68
5.2 Activities of UCD. *Adapted from ISO 13407:1999 (ISO, 1999) and (Jokela et al., 2003).* 73
5.3 Overlaps between of Action Research (AR), UCD, HCI and Usability engineering. . . . 73
5.4 Usability framework. *Adapted from ISO 9241-11:1998 (ISO, 1998).* . . . 76
5.5 Case studies map. . . . 83
5.6 Research iterations. . . . 84

6.1 Typical requirements gathering compared to the one applied in this case study. . . . 101
6.2 Example of a simple decision tree about transport modes. . . . 104
6.3 Open Data Kit (ODK) Collect User Interface. *Source: Open Data Kit (2015b).* 106
6.4 User interfaces for Anti-Poaching system . . . 107
6.5 Part of decision tree regarding poachers' camps. . . . 108
6.6 Mbendjele member making an observation. © *Jerome Lewis, ExCiteS group* . 113
6.7 Observations per day. . . . 114
6.8 Clicks per visual item. . . . 115

7.1 Countries that have signed a Voluntary Partnership Agreement (VPA) with European Union (EU). *Data from Forest Law, Enforcement, Governance and Trade (FLEGT).* . . . 121
7.2 Sapelli Platform Architecture. . . . 125
7.3 User interfaces produced by Sapelli. . . . 127

7.4 Different versions of Android's home screen. *Image a © Android; Image b © Samsung; Image c © HTC* 128
7.5 Different home screen based on the allowed applications. 129
7.6 User Interface (UI) representation of the decision tree designed in collaboration with Forests Monitor, CAGDF and local communities. . . 130
7.7 Training and introduction steps. 134
7.8 Training and mapping sessions. *© Jerome Lewis, ExCiteS group* 134
7.9 Waiting animation. 136
7.10 Examples of pictorial icon categories: (a) literal use (b) categorical use (c) metaphorical use. *Cacao fruit 🅭 Forest and Kim Starr, used under CC BY 2.0; Forest Fruit © Matthias Stevens, ExCiteS group; Nuts 🅭 Kate Ter Haar, used under CC BY 2.0; Tree © Michalis Vitos, ExCiteS group;* 137
7.11 Problematic and challenging UIs for participants. 139
7.12 Languages used during training and usability evaluations. 140

8.1 Decision tree for audio feedback example. 150
8.2 UI for audio feedback example. *Icons © Flat Icon* 151
8.3 Case studies map. 155
8.4 Decision tree designed in collaboration with CIB. 156
8.5 Training and introduction steps. 157
8.6 Training sessions conducted by research assistants. *© Michalis Vitos, ExCiteS group* 157
8.7 Part of decision tree used for *Congolaise Industrielle des Bois* [Congolese timber industry] (CIB) trials. 158
8.8 Accuracy performance for non-audio and audio tasks. 161
8.9 Completion time (in seconds) for non-audio and audio tasks. 161
8.10 Clicks per item for non-audio and audio tasks. 162
8.11 Prototype version of Tap&Map. 165
8.12 Prototype UIs for Tap&Map. 167
8.13 Icons that caused confusion during Tap&Map. 169

A.1 Sapelli Architecture. 221
A.2 Part of a Sapelli decision tree developed with international NGO Forests Monitors. *Forests Monitor (2013).* Monitoring App for Android. URL: *http://www.forestsmonitor.org/fr/capacity_building_congo_ii/572554 (Accessed on 10th Aug. 2015).* 222
A.3 Prototype version of Tap&Map. 224
A.4 Monthly sales. 233
A.5 Annual sales. 233
A.6 Break-even Analysis. 235
A.7 Projected Profit and Loss. 236

B.1 PDA device compared to Android smartphone. *Juno SC © Trimble; Xcover © Samsung* 246

B.2 Hatsuden Nabe charging pot © *Jerome Lewis, ExCiteS group* 248
B.3 Data collection actors. 251
B.4 Pattern unlocking mechanism. 255
B.5 User interface for distance estimation. 256
B.6 Visualisation tool for places observed from an estimated distance. *Map layer © Google Maps.* 257
B.7 User interfaces for audio recording. 258

C.1 CyberTracker's User Interface. *Source: Cybertracker (2015).* 262
C.2 EpiCollect. *Source: Imperial College London (2015).* 263
C.3 Imogene UI on the left and FrontlineSMS Management App on the right. *Source: Imogene (2015) & FrontlineSMS (2015).* 264
C.4 Poimapper User Interface. *Source: Poimapper (2015a).* 265
C.5 KoBo Collect. *Source: KoBo (2015).* 266
C.6 Magpi data collection app. *Source: Magpi (2015a).* 266
C.7 ODK Collect User Interface. *Source: Open Data Kit (2015b).* 266

F.1 Example of XForms compared to the Sapelli Extensible Markup Language (XML) form definition. 314
F.2 Sapelli Platform Architecture. 316
F.3 Lines of code for Sapelli platform as of May 2013. 318
F.4 Sapelli code overview. 319
F.5 Sapelli XML example of a survey about transport modes. *Tree Icons © Flat Icon; Underground logo © TfL; Bus photo © Michalis Vitos, ExCiteS group* 322
F.6 Sapelli XML detail of transport modes form. 324
F.7 Different versions of Android's home screen. *Image a © Android; Image b © Samsung; Image c © HTC* 330
F.8 Different home screen based on the allowed applications. 331
F.9 Configuring Sapelli Launcher. 332

I.1 Sapelli v2 Platform Architecture. 353
I.2 Project Management UI 354

List of Tables

3.1 Distribution of major Pygmy groups. *Adapted from Bahuchet (2012)*. 30
3.2 Challenges and requirements. 35

5.1 Usability measures. *Adapted from Welie et al. (1999)* 77
5.2 Usability measures according to Dix. *Adapted from Dix et al. (2003)*. 78
5.3 Research phases and methodologies applied. 85

6.1 Collected data. 113

7.1 Communities visited in field evaluation ordered by date of visit. 133

8.1 Communities visited in field evaluation ordered by date of visit. 154
8.2 Audio feedback results 160
8.3 Decision tree results in relation to education and technology familiarity. 163
8.4 Tap&Map results relation to education and technology familiarity. . . . 168

9.1 Sample size per case study. 194

A.1 Start-up requirements summary 219
A.2 Sales Forecast by services. 232
A.3 Sales Forecast by customer group. 232
A.4 Personnel Plan 234
A.5 Pro Forma Profit and Loss 237

B.1 Functional requirements for Anti-Poaching tool 241
B.2 Devices comparison. 247
B.3 Comparison of evaluated platforms. 254
B.4 New and recurring functional requirements for Anti-Poaching tool . . . 259

C.1 Project management – Expertise required to set up a new project. . . . 268
C.2 Form features. 269
C.3 Data synchronisation. 271
C.4 Sensors support. 272
C.5 Data visualisation and analysis. 274

F.1 Functional requirements for data collection platform 307

F.2 SMS cost per device. 315
F.3 Sapelli code contribution. 320
F.4 Sapelli XML Tags. 321
F.5 New and recurring functional requirements for Sapelli platform 332

I.1 Functional requirements for Sapelli platform 349
I.2 Sapelli v2: Features contribution. 351

List of Listings

6.1 Part of Anti-Poaching XForms implementation 104

8.1 XML example of audio feedback 151
8.2 Sapelli log interactions 152

D.1 Anti-Poaching XForms implementation 277

F.1 Sapelli XML data export 327
F.2 Sapelli CSV data export 327

G.1 Transportation Example in Sapelli XML 335
G.2 Transportation Example in XForms 336

List of Acronyms

ACD Activity-Centred Design.
ACM Association for Computing Machinery.
AR Action Research.

CAGDF *Cercle d'Appui à la Gestion Durable des Forêts* [Circle of Support for Sustainable Forest Management].
CEGE Civil, Environmental & Geomatic Engineering.
CFA Communauté Financière Africaine.
CIB *Congolaise Industrielle des Bois* [Congolese timber industry].
CSOs Civil Society Organizations.
CSV Comma Separated Values.

DAC Development Assistance Committee.
DRC Democratic Republic of the Congo.

EEA European Environment Agency.
EPSRC Engineering and Physical Sciences Research Council.
ERC European Research Council.
EU European Union.
ExCiteS Extreme Citizen Science.

FLEGT Forest Law, Enforcement, Governance and Trade.
FPIC Free, Prior and Informed Consent.
FPP Forest Peoples Programme.
FRs Functional Requirements.
FSC Forest Stewardship Council.

GATT General Agreement on Tariffs and Trade.
GDP Gross Domestic Product.
GIS Geographic Information Systems.
GNI Gross national income.
GNP Gross national product.
GPS Global Positioning System.

HCD Human-Centred Design.

HCI Human-Computer Interaction.
HCI4D HCI for Development.
HHI Harvard Humanitarian Initiative.

ICT Information and Communications Technology.
ICT4D Information and Communications Technologies for Development.
IDE Integrated development environment.
IETF Internet Engineering Task Force.
IM-FLEG Independent Monitoring of Forest Law Enforcement Systems and Governance.
IMF International Monetary Fund.
IP Intellectual Property.
IQ Intelligence Quotient.
ISO International Organization for Standardization.
IT Information Technology.
IxD Interaction Design.

JVM Java virtual machine.

LIC Lower-Income Country.

MDGs Millennium Development Goals.
MEF Ministry of Forest Economy.
MIC Middle-Income Country.

NFC Near Field Communication.
NFMS National Forest Monitoring Systems.
NGO Non-Governmental Organization.
NPFE Non-Permanent Forest Estate.

ODA Official development assistance.
ODK Open Data Kit.
OS Operating system.

PAR Participatory Action Research.
PDA Personal Digital Assistant.
PFE Permanent Forest Estate.
PGIS Participatory Geographic Information Systems.
PIN Personal Identification Number.
PLA Participatory Learning and Action.
PRA Participatory Rural Appraisal.

R&D Research and Development.
REDD Reducing Emissions from Deforestation and Forest Degradation.
REM Resource Extraction Monitoring.

RoC Republic of the Congo.
RQ Research Question.

SaaS Software as a Service.
SDGs Sustainable Development Goals.
SDK Software Development Kit.
SDS Spoken Dialogue Systems.
SMEs Small and medium-sized enterprises.
SMS Short Message Service.

TEK Traditional Ecological Knowledge.
TTS text-to-speech.
TUI Tangible User Interface.

UCD User-Centred Design.
UCL University College London.
UCSD University of California San Diego.
UI User Interface.
UIS UNESCO Institute for Statistics.
UN United Nations.
UNDP United Nations Development Programme.
UNESCO United Nations Educational, Scientific and Cultural Organization.
UNFCCC United Nations Framework Convention on Climate Change.
UNICEF United Nations Children's Fund.

VPA Voluntary Partnership Agreement.

WCS Wildlife Conservation Society.
WRI World Resources Institute.
WWF World Wildlife Fund.
WWW World Wide Web.

XML Extensible Markup Language.

1 Introduction

> *Earth provides enough to satisfy every man's needs, but not every man's greed.*
>
> — **Mahatma Gandhi (1869 – 1948)**
> (Civil rights leader)

Sustainable management of natural resources is one of the fundamental challenges of our age. Local and indigenous communities often possess unique knowledge about the natural resources on which their livelihoods depend. This Traditional Ecological Knowledge (TEK) is increasingly recognised as critical for sustaining these resources (Huntington, 2011; Berkes, 2012; Jensen et al., 2012). Recent technological developments, and growing acceptance of different forms of knowledge, mean that participatory citizen science is seen as a promising solution to achieve long-term management of key environments with greater respect for, and an active role accorded to, local communities (Ehrlich and Ehrlich, 2012; Bonney et al., 2014). In addition, '*on the ground*' data collection can provide a '*triangulation*' of the reality and provide ground truth (Wulf et al., 2013).

However, this TEK is difficult to capture in a digital format, in particular given the environment in which many communities live and their lack of technical knowledge. Yet, their knowledge is required in digital form to reach a wide audience and particularly those stakeholders who need to base their decisions on the knowledge provided. For instance, stakeholders such as logging companies that operate in the rainforest, require accurate mapping of local resources that are important financially and culturally for local communities, in order to be excluded from future cutting sessions (see chapters 7 and 8). This research explores how Information and Communications Technology (ICT) tools that enable community members to collaborate with their peers to document local environmental conditions and knowledge, and share that information with relevant outsiders, can be designed and evaluated. More specifically, it seeks to enable vulnerable communities to conduct their own environmental monitoring or mapping using mobile devices with the purpose of asserting their rights, managing responses to ecological changes, or initiating a communication channel with policy makers and other stakeholders.

1.1 Related Work

This section endeavours to briefly describe the related work and identify the gap in literature that this thesis tries to fill. A more extended version of the literature review is presented in chapter 4.

The world is highly unequal with more than one billion people living with less than a dollar per day (UNMP, 2006; Shah, 2015). This inequality is reflected by the fact that 774 million people worldwide (1 out of 5 adults) don't have access to education and subsequently can't read and write (UIS, 2013). However, the situation is dramatically worse in Central Africa and is highly correlated with national wealth and Gross Domestic Product (GDP) per capita (UIS, 2013). In remote parts of Lower-Income Countries (LICs), social infrastructures and services, such as hospitals or schools, are non-existing or poor, resulting in high illiteracy levels, especially amongst remote settled and forest communities of the area (Ohenjo et al., 2006).

Information and Communications Technologies for Development (ICT4D) is the use of ICT for international development. The idea is that the proliferation of ICT infrastructures in a country will lead to further socio-economic development and assist in the improvement of the well-being (Traunmüller and Lenk, 1996; Bhatnagar and Patel, 1998; Heeks, 2009). The potential of ICT has been also recognised in the UN's Millennium Development Goals (MDGs) (UNDP, 2015c). ICT4D systems come in a large variety and support different needs depending on the situation, from health (Grover et al., 2009; Sherwani et al., 2009) and agriculture (Plauche et al., 2006; Veeraraghavan et al., 2007; Patel et al., 2010) to education (Wagner et al., 2005) and e-governance (Backus, 2001). HCI for Development (HCI4D), on the other hand, explores how these interactive ICT platforms and applications should be designed to be appropriate for users in the LICs (Anokwa et al., 2009; Ho et al., 2009).

As it will be described in detail in section 4.1, a considerable amount of HCI4D and ICT4D literature suggests that language and literacy are major barriers to the use of modern technology and mobile devices (Chipchase, 2005; Chipchase, 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2009; Chaudry et al., 2012; Kodagoda et al., 2012), as most User Interfaces (UIs) heavily depend on textual and numerical information. Numerous studies have attempted to identify guidelines, recommendations and principles for designing more effective UIs for semi or non-literate users and propose the use of interfaces free of textual and numerical information (Grisedale et al., 1997; Huenerfauth, 2002; Shakeel and Best, 2002; Ghosh et al., 2003; Parikh et al., 2003; Chipchase, 2005; Lewis and Nelson, 2006; Medhi et al., 2006; Bhamidipaty and Deepak, 2007;

Sherwani et al., 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2011). A large and growing crop of literature on HCI for non-literate and illiterate users pays particular attention on (a) improving the usability of current mobile or web applications such as the phone book (Chipchase, 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008); (b) improving participants' access to digital information, often relating to health (Grover et al., 2009; Sherwani et al., 2009; Brown et al., 2012) or agriculture (Plauche et al., 2006; Veeraraghavan et al., 2007; Patel et al., 2010); and (c) providing finance services to participants (Parikh and Lazowska, 2006; Medhi et al., 2009). Researchers experiment with colours, symbols and icons to avoid textual components (Grisedale et al., 1997; Huenerfauth, 2002; Ghosh et al., 2003; Parikh et al., 2003; Medhi et al., 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008), while others propose the use of rich media (Gandhi et al., 2007; Medhi et al., 2009; Ladeira and Cutrell, 2010; Medhi et al., 2011) or spoken dialogue systems (Plauche et al., 2006; Plauché and Prabaker, 2006; Boyera, 2007; Sherwani et al., 2007, 2009).

As it will be presented in detail in section 4.1.2, when it comes to data collection, as is required for the capture of TEK, digital forms offer more efficient and convenient data collection with fewer errors compared to paper-based surveys (Stanton, 1998; Pundt, 2002; Lefever et al., 2007; Thriemer et al., 2012). Hence, in the context of ICT4D such as environmental management, sustainable livelihood or conservation projects in LICs, mobile data collection platforms running on PDAs or mobile phones are gaining popularity. Platforms like Open Data Kit (ODK) (Anokwa et al., 2009; Hartung et al., 2010) and EpiCollect (Aanensen et al., 2009), use mobile phones and smartphones to facilitate form-based data collection, where forms are uploaded in a centralised database, and offer tools to visualise and analyse the results. The popularity of digital collection in LICs can be reflected by the myriad of projects that collect information from health (Anokwa et al., 2012; Rajput et al., 2012; Miller et al., 2014; Underwood et al., 3013), to tracking water access (Chaudhri et al., 2012; Champanis and Rivett, 2012; Hartung, 2012, p. 62) and to household surveys (Kateera et al., 2015; Rey-Moreno et al., 2016; Hammond et al., 2017). In addition, in Participatory Learning and Action (PLA) and Participatory Geographic Information Systems (PGIS) initiatives, participatory mapping is a very common methodology for researchers to obtain local knowledge and it is used in many projects in LICs. Although such platforms are heavily used in an ICT4D context, they were designed with literate users in mind and their interfaces heavily depend on textual interactions. As a result, in all the above-mentioned examples, the process of collecting the data and importing it into the digital tools is performed by people who are literate and tech savvy to operate the data collection software, or by expert cartographers with the communities' active assistance.

However, there are a few examples in the ICT4D literature, where mobile devices were handed to semi or non-literate participants in order to record observations. CyberTracker (Cybertracker, 2015), one of the very first data collection platforms, targeted hand-held computers or PDAs (Lane et al., 2010) and was designed for semi-literate animal trackers to record observations (Spinney, 1998; Hartung et al., 2010). It later evolved into a generic data collection tool used in other conservation projects (Parr et al., 2002; Douman, 2006; Ansell and Koenig, 2011; Ens, 2012). In a similar vein, Lewis (Lewis, 2012b) describes the collaboration between a forest tribe and the logging company to provide the community with PDA devices running bespoke software with an interface consisting of pictorial icons, to record the locations of important resources. Nowadays both platforms are outdated, primarily because they relied on expensive and equally outdated devices that lack the processing power and built-in sensors of today's smartphones. Nevertheless, both examples suggest that pictorial decision trees are appropriate and effective as a classification tool and UI for non-literate participants. In these, the structure of a 'decision tree' is a type of diagram that represents a question which the participant has to answer. The leaves of the structure represent the final answers to the question, while the in-between nodes represent categories or groups that lead to the answers.

On the other hand, as it will be explained in section 4.3, recent studies in HCI4D point out that because low literacy levels are usually the result of a lack of formal education, such people may also struggle with cognitive abilities besides reading and writing (Katre, 2006; Linden and Cremers, 2008; Brown et al., 2012; Medhi et al., 2013). In studies involving illiterate people in India, Medhi et al. (2013) found that underdevelopment of skills such as conceptual abstraction and categorisation may explain why non-literate users perform worse than literate users when navigating UIs even when they are text-free (Medhi et al., 2010; Medhi et al., 2010; Medhi et al., 2012; Medhi et al., 2013). Brown et al. (2012) suggest that decision trees (and hierarchical menu structures) in combination with abstract icons are too complex for illiterate people and pose a major challenge. Additionally, over the past century, a significant increase on human performance on Intelligence Quotient (IQ) tests was revealed in different parts of the world (Flynn, 2009). This phenomenon is named the '*Flynn effect*' after James Flynn who had an essential contribution to recognising, studying and measuring it (Flynn, 2009). Amongst the proposed causes, Flynn suggests that the increase is not an actual increase in intelligence rather than an increase in abstract problem solving (Flynn, 1987), which could be partially explained by improvements in education (Neisser, 1997; Marks, 2010).

Research indicates that usability i.e. perceived usefulness and ease-of-use, and satisfaction play the leading role in the acceptance and adoption of a technology (Davis, 1989; Bagozzi et al., 1992). In the case of collaborative data collection, the lack of usability of an ICT solution can negatively influence the validity of the collected data and thus impact the success of an environmental monitoring project. However, as explained above, there seems to be a gap and contradiction between ICT4D and HCI4D in regards to the UI and especially to the appropriateness of decision trees; an example of this is the lack of research into the usability of pictorial decision trees. On the one hand, ICT4D practitioners and researchers report success stories from the field (Lewis and Nelson, 2006; Lewis, 2007, 2012b; Cybertracker, 2015), while on the other, HCI4D researchers support the argument that due to the abstract nature of decision trees, they are not applicable for non-literate user groups (Katre, 2006; Linden and Cremers, 2008; Medhi et al., 2010; Medhi et al., 2010; Brown et al., 2012; Medhi et al., 2012; Medhi et al., 2013).

As there is still much uncertainty regarding the effectiveness of decision trees as UIs for data collection with non-literate communities in ICT4D contexts, it is essential to explore alternative methods for enhancing the usability of decision trees. Research has shown that providing information across different human senses can have an impact on a participant's performance (Brewster et al., 1993; Lim et al., 2013). In the rest of this section, the use of audio and physical interfaces is explored to improve participant's performance.

As it will be presented in section 4.4, in ICT4D projects, audio clips recorded in the local language have been employed by researchers to assist rural users in India to perform micro-finance transactions (Parikh and Lazowska, 2006; Parikh et al., 2006). Similarly, Medhi et al. (2006) used audio clips in applications targeting low-literate users to access job seeking information and map navigation clues on a digital map. Other examples of audio recordings used in ICT4D projects, include the use of Spoken Dialogue Systems (SDS) where the user has to call a telephone number and follow the instructions to get access to the provided information (Plauche et al., 2006; Sherwani et al., 2007; Agarwal et al., 2009; Grover et al., 2009; Sherwani et al., 2009; Patel et al., 2010). As seen in the above scenarios, audio and SDS have shown promising results and therefore it would be interesting, in situations were decision trees were deemed inadequate, to augment the decision trees with audio cues that would reduce the cognitive load on participants and potentially increase their abstract problem solving.

As it will be presented in section 4.4, recently there has been a growing interest in forms of interaction that combine physical objects and graphical interfaces (Shaer, 2009; Jensen et al., 2012), usually referred as Tangible User Interfaces (TUIs). Providing a link with the real world and building on users' knowledge on how to interact with physical objects can improve participants' confidence (Rekimoto et al., 2001). In terms of ICT4D and HCI4D, there are very limited examples of physical interfaces being used to provide non-literate users with interfaces for communicating with digital technology. Parmar et al. (2009) discuss the use of TUIs as a mechanism to access health information and report promising results. However, in situations were decision trees were deemed inadequate, it would be interesting to explore whether TUIs can facilitate data collection and improve data collection due to the increased affordances and embodied cognition.

1.2 Research Aims and Objectives

In conclusion, one of the most pressing challenges when designing ICT applications for remote communities in LICs, is that users might have little or no formal education. The lack of education has been proven to be a major obstacle in the use of technologies and most of existing work in the area tries to mitigate this by designing text and numerical free UIs. However, there is a contradiction in the literature whether text-free structures, like pictorial decision trees, can be a universal approach and tackle the illiteracy challenge.

This research aims to explore the advantages and limitations of decision trees when employed as user interfaces on mobile devices to permit non-literate forest people to capture environmental data. It will do this by focussing on three aspects of the problem:

- The appropriateness of decision trees and their abstraction and complexity;
- The use of other sensory information to support decision trees;
- The use of physical objects to support data capture for TEK.

Additionally, this thesis endeavours to identify and present the challenges of designing and evaluating pictorial decision trees and alternative interaction modes with non-literate participants in the Congo Basin. The detailed research questions of the thesis are presented in section 5.1, on page 63.

1.3 Research Overview

As explained in detail in section 5.2, given the scale of the issue of sustainable development and the inadequacy of existing paradigms it is clear that there is a need for interdisciplinary approaches to tackle the issue. As a result, this research has been conducted as part of work carried by the Extreme Citizen Science (ExCiteS) research group that aims to enable and study the participation of lay people in citizen science activities in general, and participatory environmental monitoring and mapping in particular. Within ExCiteS, an Action Research (AR) approach was followed for collaborating with different indigenous communities and stakeholders.

As it will be presented in section 5.2, from a methodological standpoint, this individual research, conducted within ExCiteS, is mostly related to the fields of ICT4D as the primary question to be explored is whether decision trees 'work'. Therefore, it follows an engineering approach of problem solving and employs usability engineering methods to evaluate the solutions. It does however differ from typical empirical user studies of usability engineering, due to the difficulties in conducting highly controlled lab evaluations as this work was conducted 'in the wild' (see section 4.2.4). Thus, the applied methodology borrows principles of AR, and User-Centred Design (UCD) which use systematic observation and data collection methods focused on real world problems and situations. Typically UCD is characterised by multiple experimental iterations with the end users. However, in the case studies of this research, access to participants was restricted by a series of challenges: distance, costs and logistics for organising a field trip and getting in contact with participants; stakeholder expectations which do not always match with our research priorities; cultural barriers; and time constraints.

As noted in section 5.3, this thesis consists of three case studies, all taking place in the Republic of the Congo (RoC) and focusing on enabling local communities to participate in socio-environmental monitoring schemes. Hence, these case studies provided the opportunity to conduct research on the appropriateness of decision trees as UIs to capture geographical data in order to support these schemes. The three studies are themselves independent case studies and were conducted in collaboration with different communities and stakeholders. As a result, each case study had different requirements but they are highly connected since the core challenges and goals were similar.

Following an UCD approach, this research composed of three iterations, and each case study provided the basis for further research depending on the results of the previous. As, however, will be presented in subsequent chapters, in each of the case studies there were multiple sub-iterations while in the field, in order to improve both the prototypes and the approach.

A brief overview of the case studies is presented in section 5.3, while each individual case study is later independently and in depth presented in following, separate chapters (chapters 6 to 8). Finally, since this research was carried out within a research group, it is necessary to present the author's personal contribution per case study, which is illustrated in section 5.3.4.

1.4 Contribution

This section provides an overview of the findings and contributions made in this thesis, while a detailed discussion of the contributions is presented in chapter 9.

Perhaps the most significant finding of the thesis is that while pictographs are appropriate for non-literate participants, pictorial decision trees are not appropriate for them. The vast majority of participants had no issues understanding **pictographs** when displayed as flashcards or as single icons. However, pictographs imposed many challenges when introduced within pictorial decision trees, and especially when they represented categories or navigational icons. The overall hierarchical structure in combination with the abstract or metaphorical nature of certain pictographs posed great challenges to non-literate participants. Therefore, it is advocated that pictographs, that are co-designed with the communities, should be used, but pictorial decision trees should be avoided in cases where low-literacy or non-literacy prevails.

Alternatively, **physical interfaces** and **audio interfaces** should be used to improve participants performance and satisfaction. For example, physical interfaces proved to dramatically increase participants' performance, while they are not correlated with literacy levels, age or gender. However, physical interfaces come with many logistical issues of designing and managing physical objects, while they also have a negative impact on efficiency (time needed for a participant to complete a task). Audio interfaces significantly increase participants' satisfaction and subsequently they can increase their engagement with the project. As it will be presented in section 4.2, usability and user satisfaction play an important role in accepting and adopting a new technology. In the case of community mapping, user satisfaction can also impact the validity and results of the project. Hence, audio feedback can positively impact the training and mapping sessions, since it provides the participants with a playful and comforting system. However, audio interfaces do not have an impact on participants' performance, they negatively influence efficiency and can be annoying for highly trained participants.

Finally, data collection schemes should shift regularly depending on users needs and requirements. However, all the suggested solutions have a notable limitation that the options offered for data collection are strictly predefined during the design phase of the project or survey. In other words, participants are restricted to the icons offered in the pictorial decision tree survey, or by the Near Field Communication (NFC) cards they are given for use with a physical interface, without having the option to make an '*other*' observation. This limitation means that a monitoring project should be regularly followed-up and continually adapted to match all the stakeholders' needs and requirements. If participants are unable to capture what they believe to be important, they might lose interest for the project or this might cause friction between the community and the different stakeholders.

In terms of contextual understanding & evaluation methods, the most compelling implication is that given the very challenging context of working in LICs, the initial capturing of requirements can take place by employing a proxy with a firm understanding of the context, the issues and the challenges. Next, in terms of evaluation, evaluating via a proxy can be problematic; evaluating via text logs can reveal a list usability issues; inspection methods should be used with caution and their results should be cross-referenced with other methods (see section 9.3). Finally, from the list of **test methods** available to researchers, this thesis showed that *thinking aloud* should be avoided; *interviews* should be used with caution; while *field observations* and *field evaluations* are the most appropriate for the given context (see section 9.3).

1.5 Writing Conventions and Terminology

This sections describes the writing conventions, and defines a number of terms that are used throughout this thesis.

Lower-Income Countries and Middle-Income Countries: Throughout this thesis, the terms Lower-Income Country (LIC) and Middle-Income Country (MIC) are adopted. These terms were defined by The World Bank to classify countries based on their Gross national income (GNI) per capita. They were used instead of2 out-dated terms such as *Third world countries*, *Developing countries*, *Emerging countries* and *The global South* (Silver, 2015; The World Bank, 2015), as the author feels the former are more politically correct.

Community: According to Cambridge dictionary (2016), a community is '*the people living in one particular area or people who are considered as a unit because of their common interests, social group, or nationality*'. In this thesis, the word community is primarily used to describe forest, agricultural and fishing groups of people that live in or around the rainforest in the Congo Basin (see chapter 3). The size of each community varies, but it is normally in the range of 10-150 people that are interested in participating in citizen science schemes and collect data regarding their local environment and their TEK. In other occasions, the word community is used to describe any group of people who are concerned by specific issues and would be benefited by using the ICT products of this research to capture data in an effort to resolve these issues.

Non-literate versus illiterate: At this point, it is also necessary to disambiguate between a *non-literate* from an *illiterate* person. According to Encyclopædia Britannica (2015) a non-literate society is:

> *a people or culture without a written language. The term non-literate is distinguished from 'illiterate', which indicates a member of a literate society who has not learned to read or write.*

Thus, in this thesis the terms are used to indicate communities or people that have no culture of written language and therefore are non-literate, and communities where members have not learned to read or write and thus are illiterate. As described in sections 3.2 and 4.1.1, both non-literacy and illiteracy are obstacles when introducing ICT technologies and a major challenge that this thesis attempted to tackle.

Participant versus user: Throughout the thesis, the term *participant* is used to address the people who take part in the user-centred design (see section 5.2.2) approach to design, evaluate and finally use the ICT prototypes and tools. The term participant is used to demonstrate the active involvement of the communities in our common effort to tackle the challenges, develop and improve the ICT solutions. In addition, in AR the term *participant* is preferred over *user* to show the active involvement of people as partners in the research process (see section 5.2.1).

However, this thesis also contains technical sections where typical requirement analysis and IT system design is described. In computing, the term *user* is used to describe a person who uses a system or an application without having or needing the expertise to understand the underlying architecture and complexity (The Jargon File 4.4.7, 2003). In these technical sections, the term *user*, and in a few occasions *actor*, is used to address the person who interacts with the system either directly or indirectly. Additionally, in Human-Computer Interaction (HCI) the term *user* is commonly used to describe a person that interacts with a computer (or mobile) application as part of his everyday routine (Dix, 2003).

1.6 Outline

The thesis is divided in the following chapters:

Chapter 2: Motivation

In this chapter, the rational of this research is presented. To understand the ambition and the importance of this research, the broader societal context if firstly framed. Then, after sketching the challenge of sustainable development, the emerging areas of PLA, Citizen Science and ICT4D are outlined.

Chapter 3: Research Context

In this chapter the broad social, cultural, economic and political context of the Congo Basin where the case studies of this research are situated is presented. This will assist the reader to understand and appreciate the importance and complexities of this research. Then, the technological and social challenges that had to be tackled in order to deliver an ICT solution to communities and enable them to participate in data collection schemes are reviewed.

Chapter 4: Related Work

This chapter provides an introduction to related work and the methodological philosophies that underpin this research. The chapter starts by introducing the discipline of ICT4D and within ICT4D related work of software development for illiterate user groups and geographical data collection is explored. Next, the chapter introduces the areas of HCI and HCI4D that provide the theoretical framework for designing software for participants in LICs. Finally, the chapter explores the differences between ICT4D and HCI4D in order to identify the gap in the literature, that this thesis endeavours to fill.

Chapter 5: Overall Methodology

This chapter is devoted in the theory underpinning the methodological approach of this research in an endeavour to realise the research vision. Consequently, AR and UCD are introduced, both philosophies that encourage the close collaboration with communities and users in order to iteratively resolve issues and produce solutions. Afterwards, the usability engineering methods that were used '*in the wild*' are described, along with the methods for engaging with communities to co-design and introduce the tools for TEK capturing. Finally, this chapter introduces a brief description of the case studies of this research.

Chapter 6: Case study 1: Participatory monitoring of poaching

This chapter covers the first case study of this thesis that aimed to provide forest communities with a tool to monitor and report poaching activities. The chapter presents the work undertaken to capture the functional requirements of the case study and the work to design an ICT system that employed pictorial decision trees to capture geographical data regarding poaching. Next, the chapter provides the evaluation of the '*Anti-Poaching*' prototype, followed by the results.

Chapter 7: Case study 2: Participatory monitoring of logging

Following the first case study, this chapter goes into the design and implementation of a new data collection platform to meet the new requirements unveiled after the evaluation presented in chapter 6. In this case study, the goal was to introduce an ICT tool to forest and agricultural communities, in the Republic of the Congo, and enable them to collect data regarding the socio-economic effect of logging in their life. This chapter opens with the necessary social context of the case study and then presents the field trip to evaluate and improve the methodologies and ICT tools. Working closely with representatives from the local Non-Governmental Organization (NGO) and forest communities gave us the opportunity to identify a number of technical and interaction challenges that are later listed in the chapter.

Chapter 8: Case study 3: Participatory monitoring of logging

In this chapter, the technical work undertaken to improve the ICT tools as a result of the interaction and technical issues identified in chapter 7 is presented. As it will be demonstrated, the main issues identified were usability and interaction hurdles since the communities had no prior exposure to or familiarisation with mobile technology. Consequently, alternative interaction modes were designed and introduced. The goal, in this case study, was to introduce an ICT system that would allow forest and agricultural communities to map their valuable resources. The collected data would enable *Congolaise Industrielle des Bois* [Congolese timber industry] (CIB) to avoid these resources during future logging sessions and respect the communities' wishes. The chapter opens with an introduction to the social context of the case study, and it is followed by a description of a field trip in order to evaluate and improve the new user interaction modes. Finally, the results of our usability evaluation are presented.

Chapter 9: Discussion

This chapter wraps up this thesis and presents a discussion of the main findings, along with the strengths and limitations of the thesis. Finally a list of implications and contributions is presented.

Chapter 10: Summary and Future Work

This final chapter provides a summary of the thesis, an overview of the research work and how the research questions were addressed, along with a discussion of future work necessary to continue towards the vision of this research.

2 Motivation

> *Sustainable development is the pathway to the future we want for all. It offers a framework to generate economic growth, achieve social justice, exercise environmental stewardship and strengthen governance.*
>
> — **Ban Ki-moon**
> (Secretary-General of the United Nations)

The wider vision for this research is to provide technological means to communities for them to capture, share and apply their local environmental knowledge using scientifically accepted methods that can lead to better management of areas of unique biodiversity and improve environmental governance, environmental justice and management practices.

To understand the ambition and the importance of our research, we firstly frame the broader societal context and the source of our inspiration. For this reason, in the following section we start by identifying some of the worldwide concerns which are reflected by the United Nations' MDGs, and their successor Sustainable Development Goals (SDGs). The purpose of these goals is to promote Human Development around the world, to put people in the centre of the development process and increase their standard of living.

From the list of MDGs and SDGs, we identified sustainable development as one of the most significant development challenges humanity faces today on global and local scales. The scale of the issues involved and the inadequacy of existing paradigms mean that there is an urgent need for innovative and appropriate solutions to enable scientifically informed sustainable resource management of key environments.

As part of the proposed solution, we introduce the areas of PLA, Citizen Science and ICT4D from which we adopt knowledge and methodologies that in combination with appropriate use of technology will develop new paradigms for supporting sustainable management. This can lead to the empowerment and the support of local communities by providing them with those tools to share their environmental knowledge.

2.1 Millennium Development Goals

Although in the last decades humankind has experienced vast technological development and advances – which alleviate global issues – there is still a plethora of worldwide concerns that seem to be unresolved. In 2000, the United Nations, in their effort to identify and subsequently to address these challenges, composed a list with the most significant issues that torment humanity and set up eight international development objectives known as *The Millennium Development Goals* (United Nations, 2000; UNDP, 2015c).The agreed goals are (UNDP, 2015c):

1. Eradicate extreme poverty and hunger;
2. Achieve universal primary education;
3. Promote gender equality and empower women;
4. Reduce child mortality rates;
5. Improve maternal health;
6. Combat HIV/AIDS, malaria, and other diseases;
7. Ensure environmental sustainability; and
8. Develop a global partnership for development

The 189 nations that participated in the formation of the 2000 declaration committed to accomplish the eight MDGs by the year 2015 and therefore promote the International Development and the Human Development around the world (UNDP, 2015c).

In 2016, the MDGs were followed by the '*Sustainable Development Goals*', a list of 17 Goals introduced by the UNDP as a universal '*call to action*' to address amongst others poverty, education and gender inequality, and protect our natural environment (UNDP, 2015d). The goals, which were agreed by 193 nations, include 169 '*targets*' that should be reached by 2030 to resolve the 17 most pressing issues that humankind faces (UNDP, 2015b,d).

2.2 Human Development

Human Development is an on-going process of expanding the range of choices people have, so that to increase their standard of living, and contribute to the progress of healthy and creative lives (UNDP, 1990). Since 1990, the United Nations Development Programme (UNDP) produces an annual Human Development Report, which aims to put people in the middle of the development process and measure their well-being with more precise criteria rather than using only the national income per capita (UNDP, 2015a).

The concept of viewing development as a means to human well-being, instead of a way to accumulate commodities or financial wealth, and evaluating social policies by the effect they have on 'human good' goes back at least to ancient Greece and Aristotle (384 BC – 322 BC). As he notes in the Nicomachean Ethics (Crisp, 2000): '*The life of making money is a life people are, as it were, forced into, and wealth is clearly not the good we are seeking, since it is merely useful, for getting something else.*' Since then the idea of human well-being as the final end has appeared in the work of philosophers such as Immanuel Kant (1724 – 1804) and in the work of various economists such as Adam Smith (1723 – 1790), David Ricardo (1772 – 1823), Robert Malthus (1766 – 1834), Karl Marx (1818 – 1883) and John Stuart Mill (1806 – 1873) (UNDP, 1990).

In modern times, Schumacher (1911 – 1977) in his work '*Small is Beautiful: Economics as if People Mattered*' (Schumacher, 1973) promotes the idea that our goal as a society should be to minimize our consumption and in parallel to reach the maximum well-being. In order to achieve that he introduced the term of Intermediate Technology, that is discussed later in section 2.5, as a means to empower people.

2.3 Sustainable Development

The term of Sustainable Development appeared in the 1980s and was first coined by the Brundtland Commission as (WCED, 1987):

> *Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.*

Sustainability is possibly one of the most important challenges humanity faces nowadays at global and local scale and has environmental, economic and social aspects that should be tackled (Giddings et al., 2002). According to UN the world's population is estimated to exceed 10 billion by 2100 (UN DESA, 2011), which in combination with world development leads in global challenges such as the dramatic increase of consumption (BBC News, 2006) and increases the pressure on Earth's carrying capacity. Scientific data from various resources and most importantly from the Millennium Ecosystem Assessment (UNEP, 2005) indicate that the Ecological Footprint[1] of modern human exceeds the Earth's carrying capacity (WWF, 2010, 2012). Inevitably these global issues cause deterioration in the environment, have a global impact on biodiversity and lead to climate change. The Millennium Ecosystem Assessment (UNEP, 2005) concludes that human's impact on biodiversity and ecosystems, reduces both their resilience (their ability to adapt naturally) and bio-capacity (the ability of an ecosystem to produce biological materials and absorb waste). Finally, anthropogenic factors are considered responsible for causing a large part of the climate change on our planet (IPCC, 2007; America's Climate Choices, 2010).

2.4 International Development

The world is highly unequal with more than one billion people living with less than a dollar per day (UNMP, 2006; Shah, 2015). This inequality is reflected by the fact that 774 million people worldwide (1 out of 5 adults) don't have access to education and subsequently can't read and write (UIS, 2013); 400 million people (1 out of 18) do not have access to basic health services (WHO, 2015b); 663 million people worldwide (1 out of 11) do not have access to drinking water sources (WHO, 2015a); 2.4 billion people (1 out of 3) do not have access to proper sanitation facilities (WHO, 2015a); and finally 4 billion people (1 out of 1.8) do not have access to the Internet (ITU, 2015).

Since the end of the World War II, there have been efforts to establish methods and institutions to govern international economic interests leading to the formation of International Monetary Fund (IMF), the World Bank and the General Agreement on Tariffs and Trade (GATT) (Patterson, 2010). Since then, there were endeavours, mainly driven by the United Nations and the World Bank, to assist the least developed nations to create the necessary capacity for finding solutions to their own problems by providing development aid.

However, this economic development aid[2] has been highly criticised by economists as improper for assisting LICs (Williamson, 2008; Shleifer, 2009; Williamson, 2009).

[1] The Ecological Footprint is an approach to measure human's demands on the biosphere by examining the consumption against the Earth's ability to regenerate the resources (WWF, 2012).

[2] This economic aid is also referred as Official development assistance (ODA), a term coined by the Development Assistance Committee (DAC) (OECD, 2013).

For instance, Moyo (2010) argues that financial aid creates a vicious circle of dependency, corruption and further poverty.

In the following sections we will discuss the areas of Appropriate technology, PLA and Citizen Science that have the potential to break this vicious circle. A solution could be a bottom-up approach with use of appropriate technology and PLA techniques to improve the well-being of the least developed communities.

2.5 Appropriate Technology

Appropriate Technology is an ideological movement that originated from the work of the British economist Ernst Friedrich Schumacher and was firstly introduced in his book '*Small is Beautiful: Economics as if People Mattered*' (Schumacher, 1973). Originally articulated as *Intermediate Technology*, Schumacher's work was influenced by the Indian leader and activist Mohandas Gandhi and the '*Buddhist economics*'. Through a selection of essays, Schumacher criticises the conventional, western economists' arguments that economic growth and increase in GNP (Gross national product)[3] is a one-way solution to global problems, poverty and unemployment. According to Schumacher, increasing economic growth leads to the deepening of the gap between the poor and the rich and focusing only on the output is dehumanizing. By presenting examples such as the limited natural resources (e.g. fossil fuels) and nature's intolerance to pollution, Schumacher attempts to communicate that modern economy is unsustainable and he questions whether consumption and wealth, and commodities acquisition should be the sole end of all economic activity.

According to the author, in order to tackle these challenges, the following course of actions should be followed:

- Human well-being should be the centre of development.
- A human's workplace should primarily provide a dignifying and meaningful environment. Furthermore, these workplaces should be created in the areas that people live so that to decrease the modern tendency of urbanisation.
- Development should promote sustainability. Workplaces and the production methods should be cheap enough and composed of local, easily available materials.

[3]Gross national product (GNP) is an economic measure of a nation's economic activity in a given year, and it is an estimation of all finished goods and services produced in a country by the its citizens in that year (Investopedia, 2016).

- Human's needs and limitations should be considered during development, promoting the enoughness and appropriate use of technology.

Although appropriate technology is not a novel idea and some researchers trace its origins in the 1940s (Jéquier and Blanc, 1983), nowadays the term stands for a dynamic approach to treat development problems of developing communities (Akubue, 2000). Since Schumacher introduced the term, many authors have written about, and attempted to define the concept of appropriate technology. As a result, throughout literature it can also be found under terms such as intermediate, progressive, alternative, light-capital, labour-intensive, indigenous, low-cost, community, soft, radical, liberatory, and convivial technology (Akubue, 2000).

Morawetz stated that appropriate technology is a process of careful and intelligent techniques to make optimum use of available resources in a given environment, in order to maximize social welfare (Morawetz, 1974). Pellegrini proposed that appropriate technology when introduced to a community is a self-reinforcing process that supports the community members' local activities, growth and assists the development of indigenous knowledge (Pellegrini, 1979). In the definition by Thormann, appropriate technology is efficient in small-scale and makes intensive use of locally available resources. In terms of people, appropriate technology seeks to be compatible with their socio-culture environments and promote their benefits (Thormann, 1979). Harrison mentioned that as appropriate technology should be considered any technological effort that makes utmost economical use of a country's natural resources, capital, labour and human skills so that to achieve national as well as social goals. According to Harrison the promotion of appropriate technology means to assist the right technological selection consciously and not only letting commercial parties to make the decisions (Harrison, 1980). Betz et al. (1984) identified appropriate technology as an effort to provide the technological solutions and capabilities to influenced communities for managing their resources, their facilities and their environment.

2.6 Participatory Learning and Action

Participatory Learning and Action (PLA), formerly known as Participatory Rural Appraisal (PRA), is an approach for obtaining knowledge from local communities concerning their living conditions and their environment. The purpose of this exercise is to incorporate the gained knowledge in development projects and increase the well-being of the communities (Chambers, 1994).

According to Chambers (1997) in his book '*Whose reality counts? Putting the first last*' a common tendency in developing programs is to ignore people and the environmental factors especially in farming systems leading to development failures. In addition, as stated by Paulo Freire (1921 – 1997) development practitioners try to normalise the world by applying methods that work in the part of the world they come from (Chambers, 1997).

In order to tackle these challenges, Chambers proposes the PLA approach where '*people are put first and poor first of all*' and argues that in order to empower communities, the power should be reversed. Depending on the situation and the complexity, Chambers proposes tools such as mapping, naming, listing and comparing to collect local knowledge and see the world through the locals' eyes (Chambers, 1997). As we see in the following section (section 2.7), this local knowledge can be very important when it comes to the sustainable management of natural resources.

In the list of proposed tools, mapping is one of the most prominent and *participatory mapping* is often combined with Participatory Geographic Information Systems (PGIS) as an approach to obtain information from local communities concerning their environment (Chambers, 1994; Peluso, 1995; Corbett et al., 2006). PGIS is an approach to combine PLA with Geographic Information Systems (GIS) and produce spatial data to represent people's knowledge (Abbot et al., 1998).

2.7 Traditional Ecological Knowledge

All around the world, local indigenous communities possess unique, complex and adaptive systems of knowledge that have enabled them to manage their environments sustainably, sometimes for thousands of years (Huntington, 2011). This knowledge is termed as Traditional Ecological Knowledge (TEK) and is increasingly being recognised by environmental managers as critical for sustaining the environment (Berkes, 2012), and in the literature there are already examples of TEK being collected to promote sustainability. For instance the project 'The Suruí Forest Carbon Project' demonstrates how community monitoring can be employed for collecting carbon credits. In this, an indigenous community, through the use of technology, has provided evidence regarding illegal activities and the collection of carbon credits (Forest Compass, 2016; Rainforest Alliance, 2016). Similarly, Liebenberg et al. (2017) describes how TEK regarding rhino feeding behaviour, that was collected by community members, has contributed to novel scientific contributions.

Finally, given the significant funding being committed to the United Nations (UN) Green Climate Fund (approaching 9 billion EUR), REDD+[4] development, and the increased commitments of developed countries to dedicate 0.7% of their GDP to aid, over the next 20 years there are plenty of opportunities for local communities to collaborate with national and international NGOs and establish data collection initiatives that aim to collect environmental data and TEK in order to promote sustainability.

2.8 ICT4D

Later in this thesis, we explore the literature of ICT4D in detail (see section 4.1). However, it is necessary for understanding the wider vision of the thesis to quickly define it here.

Information and Communications Technologies for Development (ICT4D) is the use of Information and Communications Technology (ICT) for international development. The idea is that the proliferation of ICT infrastructures in a country will lead to further socio-economic development and assist in the improvement of the well-being (Traunmüller and Lenk, 1996; Bhatnagar and Patel, 1998; Heeks, 2009). For this reason, the World Bank, along with other agencies, has set up an initiative called InfoDev (Information for Development program) to study how the use of ICTs can assist their efforts to alleviate poverty and promote economic growth in developing regions (The World Bank, 1996).

ICT4D systems come in a large variety and support different needs depending on the situation from health (Grover et al., 2009; Sherwani et al., 2009) and agriculture (Plauche et al., 2006; Veeraraghavan et al., 2007; Patel et al., 2010) to education (Wagner et al., 2005) and e-governance (Backus, 2001).

However, research studying the impacts of access to ICTs reports that the results are not as expected, with many projects either failing or proving unworkable in the long term (Heeks, 2002; Sey and Fellows, 2009; Heeks, 2010; Rogers, 2011; Barnett, 2012; Doerflinger et al., 2013). For instance, an internal evaluation of the World Bank efforts to promote ICT access and adoption shows that there was a 70% failure amongst the projects (Independent Evaluation Group, 2011).

Although these results could be partially interpreted by the difficulty of discovering and measuring the impact of ICT (Sey and Fellows, 2009), a possible reason for the

[4] Reducing Emissions from Deforestation and Forest Degradation (REDD) is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development.

failure of ICT4D can be the use of inappropriate approaches and technology concepts (Doerflinger et al., 2013). Rogers (2011) identified the most common reasons for those failures and he states:

- ICT4D ideas/results are not directly connected to improving end user economic conditions;
- ICT4D ideas/results are not relevant to local context, strengths, needs;
- ICT4D ideas/results are not consistent with an understanding of infrastructure capability;
- Budget planners underestimate maintenance costs and related issues;
- Projects are supported only by short-term grants;
- Planners are not looking at the whole system;
- Projects are built on assumptions unconnected to participant input or are organisation-centric rather than planned for local realities.

Therefore, once again the importance of making appropriate use of technology in respect with local conditions and needs is high-lightened.

2.9 Citizen Science

Citizen science is understood as scientific activities in which non-professional scientists (‘*citizens*’) participate in data collection (and sometimes data processing, by supplying brain or computing power) within a scientific project (Haklay, 2013). In the last decade, a new incarnation of citizen science has appeared. The proliferation of ICT; the realisation that the public can provide free labour, skills, computing power and even funding; and growing demands from research funders for public engagement – are all trends that have contributed to motivating scientists to develop and launch new citizen science projects.

However, such projects are usually set in developed countries and the participating ‘*citizen scientists*’ are still treated as having limited capability. Sometimes they are viewed as (vehicles for) sensors (Goodchild, 2007) or data collectors (Cohn, 2008), yet they are rarely invited to analyse data or to contribute to its interpretation, even though they carried out the primary observations and may well have valuable insights. Finally, there is an implicit expectation that a participant must be well educated in order to perform a scientific task. All of these make current citizen science practice limited in its social reach, scope and geography.

In the context of international development, citizen science through the active participation of individuals can facilitate the partial achievement of the MDGs and SDGs by promoting sustainable development and sustainable resource management. For instance, one key area for developing new sustainable management paradigms is to support local people to more effectively manage areas of unique biodiversity by providing them with appropriate tools and methodologies for organising data collection and its exploitation in a way that can improve environmental governance, justice and management.

The challenge is to come up with tools and methodologies that can enable any user, regardless of his or her educational or literacy level, to understand local conditions and develop appropriate responses. Tools must be easy to use, easy to understand and, most importantly, designed to empower users to act upon the analysis generated. They must also be adapted to the specific social, economic, ecological, cultural and technical contexts for which they are intended. Finally, they must be based on valid scientific observation and analysis, such that correct conclusions may be reached.

Developing these tools, as well as a methodology through which they can be successfully deployed, requires an interdisciplinary approach. Anthropological and PLA methodologies are applied to gain a thorough understanding of the local context in each case, and to identify and engage with potential users. Human ecology, geography and development studies can all help to diagnose the challenges these communities may face, while the emergent field of ICT4D offers models for capitalising on the rapid global spread of communications technologies, and for introducing new technologies in areas or communities previously excluded.

2.10 Summary

In this chapter some of the worldwide concerns were identified that are unresolved and are sketched out by the United Nations' Millennium Development Goals (MDGs) – a list of eight international development objectives. The purpose of these goals is to promote Human Development around the world, to put people in the centre of the development process and increase their standard of living.

However, as identified, one of the most significant development challenges that humanity is facing today is the sustainable development and subsequently sustainable natural resource management. The scale of the issues involved and the inadequacy of existing paradigms mean that there is an urgent need for innovative and appropriate solutions to enable scientifically informed sustainable resource management of key environments. Although there were efforts to accomplish the millennium goals – and consequently sustainable development, most of the paradigms have failed due to lack of appropriateness and finally for not taking into account local variables.

Hence, there is a need for successful approaches that will combine citizen science principles, PLA methodologies and appropriate use of technology to develop new paradigms for supporting sustainable management. This can lead to the empowerment and the support of local communities by providing them with those means to share their environmental knowledge so they can manage these areas of unique biodiversity themselves and improve environmental governance, environmental justice and management practices (West et al., 2006; Raftree and Nkie, 2011; Lewis, 2012b).

3 Research Context

> *The hardest single part of building a software system is deciding precisely what to build. No other part of the conceptual work is as difficult as establishing the detailed technical requirements... No other part is more difficult to rectify later.*
>
> — **Frederick P. Brooks (1987)**
> (Computer architect, software engineer)

Although it has been almost 30 years since Brooks's statement, gathering detailed functional requirements and acquiring a good contextual understanding provide a firm foundation for the success of an ICT project ever since (Brooks, 1987). Deploying ICT systems in LICs, working with remote agricultural or forest communities, and putting devices designed for literate, educated people in the hands of non-literate people – so that they can collect local TEK, make in situ observations, visualise and report the results – presents numerous foreseeable and unforeseeable difficulties.

In this chapter, we review all these technological and social challenges that had to be tackled in order to design and evaluate ICT tools that explore the appropriateness of decision trees as interactions modes for geographical data collection and we explain how these challenges were identified. We open by setting the scene of the rainforest of the Congo Basin, where numerous indigenous and settled communities are inhabiting and relying on the forest for a range of ecosystem services[1]. A common denominator amongst these communities, is their intimate connection with the environment, and their willingness to protect their lifestyle which is threatened due to local issues, such as political instability, predatory market forces and rapidly expanding industrial activities, that urgently call for innovative and appropriate solutions to enable scientifically informed sustainable resource management of their environments.

[1]Ecosystem services are the benefits that humankind receives from our ecosystem (UNEP, 2005). As defined in the *Millennium Ecosystem Assessment* (UNEP, 2005), ecosystem services include *provisioning services* such as food and water; *regulating services* that affect the climate; *cultural services* that provide recreational and spiritual benefits; and *supporting services* such as soil formation.

3.1 Social context

The Congo rainforest constitutes the second largest tropical forest on earth, after the Amazon. Covering a vast area of 200 million hectares, it stretches across Democratic Republic of the Congo (DRC), the majority of Republic of the Congo, the south-east of Cameroon, the southern Central African Republic, Gabon and Equatorial Guinea. It acts as a vital climate regulator, and as a unique biodiversity centre (Zhou et al., 2014), hosting more than 10.000 species of plants, 1.000 species of birds, 400 species of mammals and 400 species of fish (UNESCO, 2010b, p. 11), including rare and under extinction animals such as the mountain gorilla (Gorilla beringei beringei) and the central chimpanzee (Pan troglodytes schweinfurthii) (Seyler et al., 2010, pp. 20, 47).

The Congolese forest is estimated to be hosting more than 29 million rural people[2], including up to 500,000 indigenous people[3], whose livelihood is closely related to the forest (Lewis and Nelson, 2006), while it is providing food, fuel, fibre and a wide range of other ecosystem services to a total of 200 million persons (Norris et al., 2010).

In general, it is possible to differentiate two main groups of people living and depending on various degrees on the rainforest for their livelihoods. The indigenous or forest people who live as hunter gatherers, and the settled Bantu and Ubangian farmers and fisher people, most commonly referred to as Bantu (Conquest, 2014; Eisen et al., 2014).

3.1.1 Indigenous people

The rainforest is home to more than 150 different hunter-gatherer ethnic groups, often referred as Pygmies by outsiders (Eisen et al., 2014, p. 11). As noted by Lewis (2002), the term 'Pygmy' is used widely in academic writing to describe physically, geographically and culturally different, indigenous peoples in equatorial Africa that however share cultural and economic practices, the most common of which is hunting and gathering and the nomadic lifestyle. The use of the term 'Pygmy' can have a negative connotation, due the discrimination against these communities. In Republic of the Congo, the usage of the term is forbidden by law (Law no.5-2011, Article 1), and the French word 'autochtone', meaning 'indigenous', is vastly used by the government and local NGOs (Conquest, 2014). In the rest of the thesis, the

[2] Population estimations vary widely, some reports suggest that there are up to 50 million people living in the Congo Basin rainforest (Eisen et al., 2014, p. 11)

[3] A recent study estimates that there are more than 900,000 Pygmies in the forests of Central Africa (Olivero et al., 2016)

term ‘Pygmy’ is used according to the academic practice, and without intention to denigrate or disrespect.

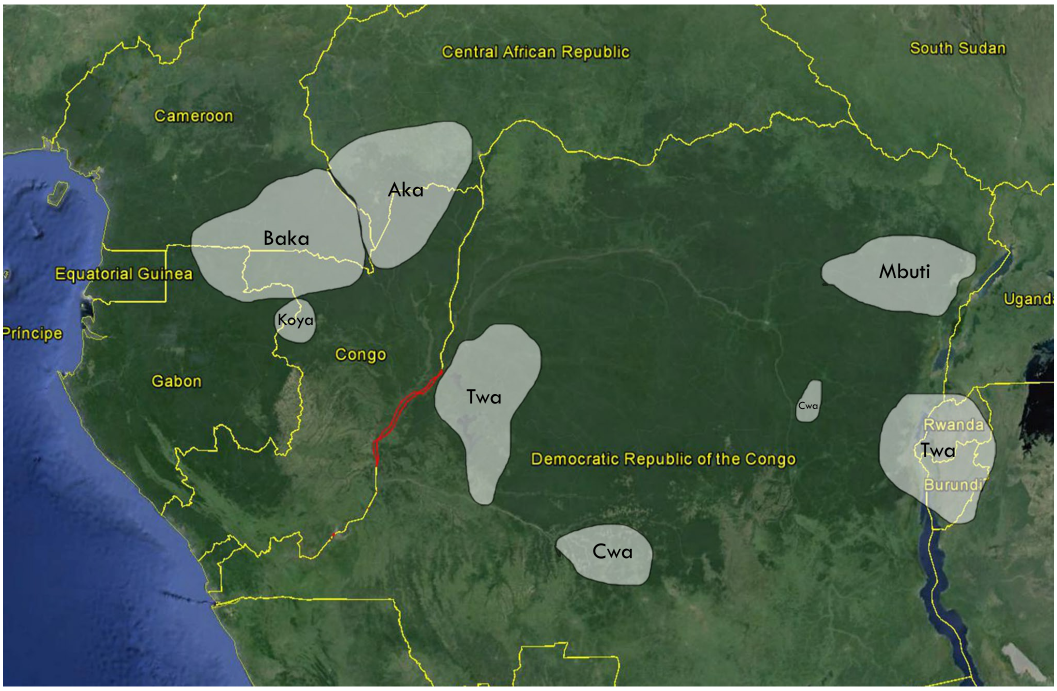


Figure 3.1.: Map of major Pygmy groups. *Adapted from Bahuchet (2006). Base layer © Google Earth Pro.*

According to Bahuchet (2012), there are approximately 20 major groups of Pygmies, distinguished by ethnic, linguistic and geographical differences (table 3.1). This is the largest and most diverse population of nomadic, hunter-gatherers that exist in the world today (Hewlett, 2014, p. 17). These groups can be found under several different names in the literature as described in table 3.1. However, amongst those, the most prominent indigenous groups, as shown in figure 3.1, are the Aka, Baka, Cwa, Mbuti and Twa.

Lifestyle

A common denominator amongst these communities is their intimate connection to the forest that they live in. They identify themselves as ‘forest peoples’ to emphasize the importance of the forest to their culture, history and livelihood (Lewis, 2001). The vast majority of communities live a nomadic lifestyle, and they are typically spending more than half of the year hunting wild animals and gathering wild produce, including fish, reptiles, caterpillars, honey and fruits (Hewlett, 1996; Lewis, 2002). According to Lewis (2002), the Yaka Mbendjele pygmies cannot imagine their lives, or their afterlives, without the forest. The dependency is so strong and clear

Table 3.1.: Distribution of major Pygmy groups. *Adapted from Bahuchet (2012).*

Name	Country	Other names
(Ba)Kola	Cameroon	(Ba)Gyeli
Bedzan	Cameroon	Medzan, Tikar Pygmies, Pygmées des Tikar
Baka	Cameroon, Congo, Gabon	Bangombe, Bibayak, Babinga
(Ba)Rimba	Gabon	Babongo
(Ba)Bongo	Gabon	Akoa, Barimba
(Ba)Koya	Gabon, Congo	(Ba)Kola
Mikaya	Congo	Bambenga
(Ba)Aka	CAR, Congo	Bayaka, Biaka, Babinga, Bambenga, BaMbenzele, Babenzele
Bofi Pygmies	CAR	Babinga
(Ba)Twa	DRC	Konda Twa
(Ba)Cwa	DRC	Bushong Twa, Kuba Cwa
(Ba)Cwa; (Ba)Tembo	DRC	Luba Cwa, Batwa, Bambote
(Ba)Sua	DRC	(Ba)Mbuti, (Ba)Kango
Asua	DRC	Bambuti, Akka, Aka, Tikki-tikki
Efe	DRC	Bambuti
(Ba)Twa; (Ba)Rhwa	DRC	Batwa, Kivu Twa, Western Twa
(Ba)Twa	Uganda	Batwa
(Ba)Twa	Rwanda, Burundi	Batwa, Eastern Twa

Note. CAR: Central African Republic; DRC: Democratic Republic of Congo; Congo: Republic of the Congo.

that the Yaka have a proverb saying *'A Yaka loves the forest as he loves his own body.'* In addition, the forest is the source of medicine and a series of materials used for constructing tools, haunting weapons, household utensils etc. (Ichikawa, 2014).

The importance of the forest for the communities is also highlighted by the cultural and spiritual significance of the forest in their lives. They regard themselves as 'children of the forest', which they view as a sacred area where the forest spirits exist. According to Ohenjo et al. (2006), Pygmies believe that they are an integral part of the forest and that they are closely connected to the spirits of the forest and of their ancestors. Lewis (2002, p. 11) describes more than 20 forest spirits and spirit performances, while *Jengi*, the spirit of the forest (also called *Djengi* or *Ejengi*), is one of the few common words amongst the various languages spoken by forest communities.

Traditionally, these indigenous communities live in small, egalitarian groups that travel frequently and settle to different areas of the forest, living in temporary huts, constructed exclusively of wild plant materials (Ohenjo et al., 2006; Ichikawa, 2014). While moving, the main source of income is haunting and gathering resources, which are either consumed by the community itself, or in many cases are exchanged to nearby settled farmer communities for cultivated products and goods such as manioc, maize and iron (Hewlett, 1996). Certain forest communities have developed strong trading relationships with specific settled communities, leading to complex economic and social dependencies (Hewlett, 1996).

3.1.2 Settled communities

In addition to the nomadic groups, the Congo Basin is home for an enormous range of Bantu and Ubangian farmer and fisher communities, living in open spaces, adjacent to the rainforest, most commonly referred to as Bantu (Conquest, 2014). These groups make a living from farming (cassava, coco, yams, oil palm, cocoa and coffee), fishing, trapping and trading (Lewis, 2002; Eisen et al., 2014). The Bantu are the cardinal traders with urban centres, selling a plethora of forest products (Lewis, 2002).

Historically, the Bantu communities composed of small groups of kin that migrated into the Congo Basin approximately 3,500 years ago (Eisen et al., 2014). The Bantu and the forest communities have lived in parallel for thousands of years and in many cases they have developed strong economic and trading relationships (Hewlett, 1996). According to Lewis (2002) they are considered 'indigenous', but their relationship with the forest peoples is characterised by strong discrimination from the Bantu towards the forest communities.

Bantu claim exclusive rights over the territories that Pygmies operate, as well as over the persons and labour of forest people (Lewis, 2002). Many Pygmies offer agricultural labour (clearing farmlands and harvesting) to Bantu communities, or they trade collected food (such as bush meat, palm-nuts, honey and leaves), which the Bantu sell for consumption in urban centres, for items uncommon in the forest such as iron and salt (Lewis, 2002).

3.1.3 Local issues

As we explained, the lifestyles in these communities vary – some are semi-nomadic hunter-gatherers (Pygmies), while others are sedentary farmers – but all depend on the forest for their livelihoods. These people are among the poorest African citizens, yet they are rarely involved in the management of the areas on which they depend. Current conservation and natural resource management efforts, supported by international organisations such as the Wildlife Conservation Society (WCS), the World Wildlife Fund (WWF) or other NGOs, often involve draconian measures which disenfranchise locals (Ichikawa, 2014). The overwhelming tendency in Central Africa since the 1990s has been to establish protected areas that exclude local people, or restrict their access, in parallel with the aggressive promotion of industrial resource extraction in adjoining areas (Brockington et al., 2006; West et al., 2006; Lewis, 2008).

Although the Congo Basin is internationally recognised as a unique biodiversity centre that has a direct impact on climate change, the forestry and resources extraction sectors are rapidly growing (Lewis, 2012b). During the last two decades, the national legal systems of the Congo Basin's countries have been reshaped to encourage international investments to control and manage forest territories regardless of the local forest peoples' needs, for instance Cameroon in 1994, Republic of the Congo in 2000, Gabon in 2001 and DRC in 2002 (Lewis, 2012b). The current political status quo divides the forest into Permanent Forest Estates (PFEs) and Non-Permanent Forest Estates (NPFEs). The permanent areas are either established as national parks and protected areas that exclude local forest people, or they are divided as logging and mining concessions. The remaining non-permanent areas are used primarily by local settled communities, leading forest peoples in vulnerable positions (Lewis, 2012b; Eisen et al., 2014).

In conjunction with the political instability, predatory market forces and rapidly expanding industrial activities, climate change is adding a new, unpredictable dimension to the rapid environmental changes experienced by the Pygmies and other forest-dependent people (Eisen et al., 2014).

As logging roads open up increasingly remote regions to commercial activities, more and more of the forest's resources are drawn out onto (inter)national trade networks and forest people watch their resource base diminishing. Addressing the needs of these groups is challenging on many levels: Local infrastructure is weak or non-existent; governance is similarly weak and undermined by corruption and resource-fuelled conflict; economies are dominated by multinationals extracting oil, minerals and timber, and increasingly promoting large scale land-use change by establishing palm oil plantations (Lewis and Nelson, 2006).

3.2 Technological and social challenges

Typically, the initial steps of a requirements analysis involve in-depth interviews with stakeholders to obtain rich understanding of the context and their needs (Robertson and Robertson, 2012). As we will explain in chapters 4 and 5, this research follows an UCD approach, and the foundation of the UCD process is specifying the context of use, identifying the users and their goals (Jokela et al., 2003; ISO, 2010). However, the vision of this research was to provide technological solutions to communities and support their efforts in capturing TEK in different areas of Central Africa by exploring whether decision trees are an effective interaction style for geographical data collection. Therefore, one of the goals was to develop a general strategy that could be applied in different contexts by communities encountering analogous environmental issues.

Hence, a more general requirements analysis was necessary to extract the technological and social challenges faced when deploying ICT systems in LIC in general, which were captured by studying the literature on ICT4D and HCI4D projects. By generalising the requirements and challenges faced, this research could be deployed in different contexts, and the outcomes could be relevant for similar researchers.

Equally important, one objective of this research is to apply the developed strategies into specific and concrete case studies, for which a specific requirements analysis was necessary to ensure that the requirements of these case studies match the generalised list extracted from the literature. This thesis describes three case studies, all taking place in Republic of the Congo and focusing on enabling local communities to participate in socio-environmental monitoring schemes. The case studies will be collectively presented in section 5.3 and then independently in separate chapters. At this section, we are focusing on the methodology for extracting the functional requirements and challenges, and comparing them to the ones found in ICT4D literature.

In the case studies demonstrated in this thesis, having direct or easy access to the stakeholders was challenging due to a series of restrictions. The primary stakeholders of the developed ICT systems were agricultural and forest communities; therefore, the participants were situated in semi-permanent settlements or temporary huts in the Congo Basin region, a very long distance (physically and conceptually) from the research base in London, UK. Travelling and meeting the participants, apart from the financial barrier, required adequate and time-consuming preparation. Due to the division of the rainforest into logging concessions, travelling into one of them without proper documentation is undesirable. It is advisable to obtain a special invitation letter from the local logging company or a local NGO, along with a local travel visa. Equally important, the lack of mobile networks and internet connection in combination with the participants' limited familiarity with and access to technology, excluded options as teleconference or other kind of electronic communications. Finally, even if travelling was straightforward or using modern technologies such as telephones was feasible, the different languages and dialects that the participants spoke would be a hurdle, as there are only a handful of people in London that can translate from the locally spoken languages such as Lingala[4], or more specific tribe-spoken languages, such as the Mbendjele, to English and vice versa.

Hence, due to logistical and practical reasons (i.e. cost, lack of invitation letter from local NGOs), it was decided that the initial requirements and potential challenges for the first case study would be also obtained from a literature review and a close collaboration with the lead anthropologist of the ExCiteS research group, Dr Jerome Lewis. Lewis has known and collaborated with the Mbendjele, one of the local forest communities inhabiting the forest of Congo Basin, since 1994. His applied research on supporting forest peoples' conservation efforts makes him a world expert on issues of discrimination, economic and legal marginalisation and human rights abuses and the most appropriate person to be interviewed in the absence of actual participants. Thus, for the first case study, focusing on the development of a tool to report poaching activities, a series of interviews with Lewis were arranged. During those, Lewis provided a thorough explanation of the background and all the relevant stakeholders, and the situation on the ground. Lewis' special connection with the communities, and his vast experience of the area was extremely valuable in sketching up the first requirements and picturing the challenges. For the next two case studies, dealing with the participatory monitoring of logging, I had the opportunity to travel, in person, in the Republic of the Congo and validate or extend the challenges identified during the first requirements analysis.

After capturing and grouping all the challenges and difficulties identified from Lewis' narratives, and also from reading the literature on local tribes and personal on the

[4]a Bantu language commonly spread throughout the north-western part of the DRC and the Republic of the Congo

ground observations, it has been observed that these were aligned with the major challenges other researchers report on various ICT4D initiatives. These challenges are grouped and illustrated in table 3.2, in order to be able to refer to them later in this thesis. As table 3.2 shows, the main challenges can be grouped into social, technological and security related. The social challenges are the most important and challenging issues that this research tried to tackle and include the various levels of literacy, from the ability to read and write to technological familiarity, and the language barriers. Equally important are the technological issues relating to the selection of mature and appropriate technologies, which are fit for the purpose of the project. While, finally, the security challenges refer to the need for designing robust and discrete solutions given the sensitive nature of the project.

Table 3.2.: Challenges and requirements.

1 Social challenges
1.1 Literacy
1.1.1 Ability to read and write
1.1.2 Numerical literacy
1.1.3 Technological literacy
1.1.4 Map literacy
1.2 Language
2 Technological challenges
2.1 Lack of power infrastructure
2.2 Lack of network infrastructure
2.3 Adverse rainforest conditions (i.e. dust, humidity) influencing electronic devices
2.4 Rough treatment by users
2.5 GPS signal reception influenced by forest canopy
2.6 Affordable equipment by NGOs or communities
3 Security challenges
3.1 Personal safety of users taking part in monitoring activities
3.2 Secure data storage and transmission

3.2.1 Literacy

According to UNESCO Institute for Statistics (UIS), the organisation responsible for monitoring international literacy, 774 million worldwide are unable to read or write (UIS, 2013). This roughly translates to 1 adult in 5 being illiterate. However, looking at the map provided by UIS, the situation is dramatically worse in Central Africa (see figure 3.2) and is highly correlated with national wealth and GDP per capita (UIS, 2013). In remote parts of LICs, social infrastructures and services, such as hospitals or schools, are non-existing or poor, resulting in high illiteracy levels, especially amongst remote settled and forest communities of the area (Ohenjo et al., 2006).

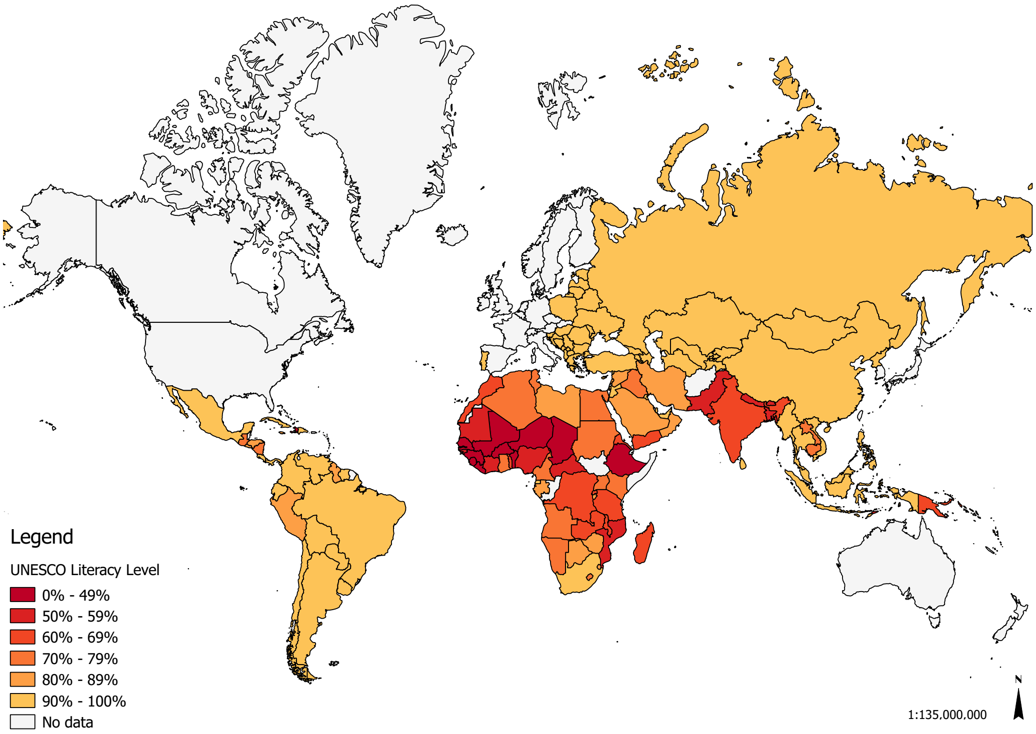
Hence, participant's low or lacking literacy is the most obvious of the challenges that had to be addressed. This covers literacy in the original sense (i.e. knowing how to read and write) as well as numeracy and so-called 'technological literacy' (i.e. the ability to use and understand ICT tools) (Chetty and Chetty, 2007; Chetty and Grinter, 2007; Hopkin, 2007). In terms of this research, since the majority of local community members that participated in the case studies lived in remote areas of the Congolese rainforest, they had never had any formal education, nor used computers or mobile phones, and had difficulty in reading the numbers on banknotes (Lewis, 2002).

Also, most of the communities, presented in this thesis, face the problem of map literacy – the ability of reading and understanding a map – as their style of living does not require the use of maps or sophisticated navigation and positioning technologies for orienting purposes (Lewis, 2002, p. 258).

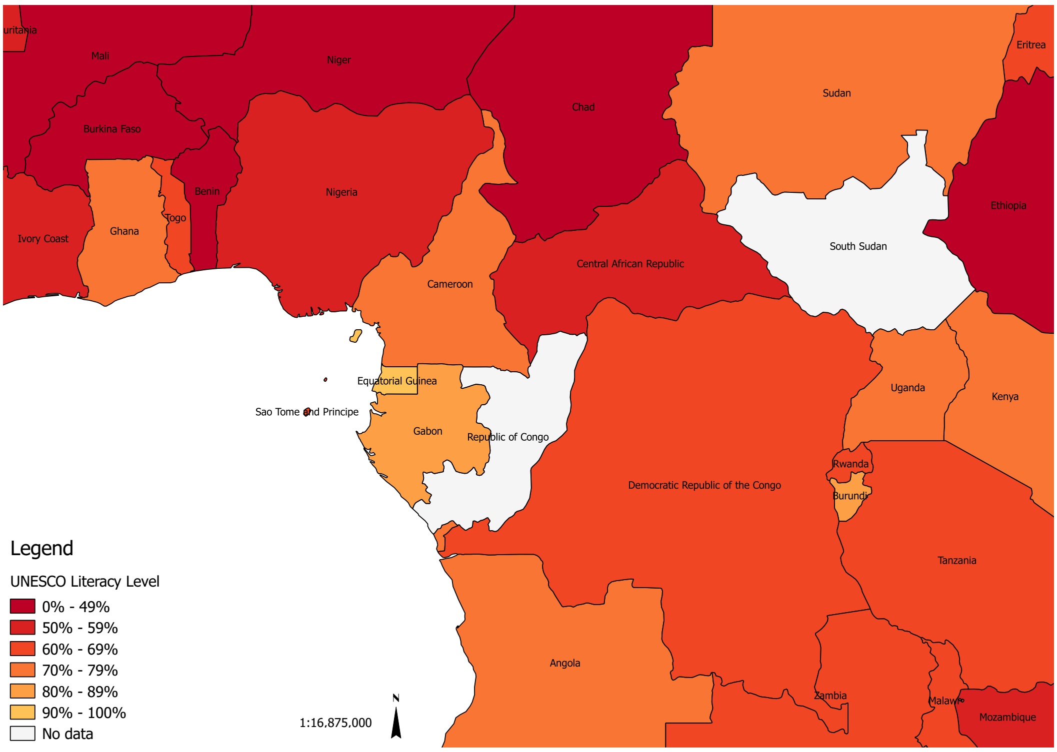
Multiple researchers have shown that non-literacy is a major obstacle in using mobile devices and interfaces, as virtually any standard UI contains textual and numerical elements (Chipchase, 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2009; Chaudry et al., 2012; Kodagoda et al., 2012).

3.2.2 Language

Literature on the impact of ICT4D, as well as on the social and cultural barriers for the adoption of ICT, suggest that language can pose an issue (Dyson, 2004; Hansen et al., 2011; Jensen et al., 2012; Touray et al., 2013; Devezas et al., 2014; Haji et al., 2014). Language can be a challenge in two forms, on the one hand language barriers can complicate the communication between participants and researchers, requiring local translators and in some cases more than one steps of translation (Gitau et al., 2010) (see section 7.5.3). On the other, English is the main language of Computer



(a) Word view of literacy rates.



(b) Congo Basin view of literacy rates.

Figure 3.2.: International literacy rates for adults. *Data from UNESCO Institute for Statistics (UIS, 2013).*

Science and is predominant in every technological artifact, limiting the access to technology to people unable to read or understand the language (Dyson, 2004).

In terms of this research, language barriers were an important challenge as the majority of the communities inhabiting the Congo Basin are speaking their own local language or different dialects. For instance, amongst the Mbendjele only a handful can speak any international languages and their own language is spoken by few outsiders. Lingala, the local lingua franca that is spread throughout part of the DRC and the Republic of the Congo, is spoken by some members of the local tribes and communities (Lewis 2002). Thus, finding translators to assist in the communication with the participants, especially English speaking translators, was equally challenging and time consuming. As a result, we had to go through multiple steps of translation (e.g. English > French > Lingala > Mbendjele), with the potential for meaning to be lost, changed or added.

3.2.3 Technological challenges

In the LICs the power grid is often unreliable with plenty of spikes and outages, causing problems like overheated and malfunctioning laptop batteries and hard disks (Parikh and Lazowska, 2006; Thinyane et al., 2006; Chetty and Chetty, 2007; Anokwa et al., 2009). In remote areas and in the rainforest however, there are usually no power facilities at all – nor does the traditional lifestyle of communities like the Mbendjele require it. This, combined with the high power demands of modern technology like smartphones and GPS receivers, poses a major challenge for many of ICT4D initiatives (Thinyane et al., 2006; Chetty and Chetty, 2007).

Furthermore, although it is fast expanding, cellular network penetration and coverage remains limited in LIC, especially in vast, sparsely inhabited areas (Parikh and Lazowska, 2006). However, since the early 2000s and the realisation of the value of the local African market for network operators, masts[5] are being erected even in small towns in remote, forested areas, specifically targeting workers receiving regular wages in resource extraction industries such as logging, plantations and mining. Deeper into the forest there is typically no network coverage, let alone Internet connectivity, which is problematic because data needs to be uploaded to and synchronised with a central database.

In relation to this research, the adverse conditions of the African rainforest (dust, mud, high humidity levels and frequent rain) and the inexperience of participants with delicate technology, add an extra layer of challenges and necessitate equipment (i.e. mobile devices, tablets etc.) that can be robust so that they do not break

[5]Offering 2G and 3G connections.

when roughly handled for extended periods of time. Furthermore, these devices should be equipped with a GPS receiver that is sensitive enough to get location fixes under dense forest canopy within a reasonable amount of time (e.g. max 5 minutes) and of adequate quality depending on the project scope (see for example section 6.3). Finally, as this research is targeting NGOs that act as facilitators, it should be relatively cheap, so as to be affordable by the NGOs and potentially indigenous communities themselves.

3.2.4 Security issues

One the most challenging problems is that of security and more specifically personal safety. Developing a generic strategy and tools that could be applied in different contexts for data collection, could lead to situations of capturing sensitive data that could endanger the communities that collect them. For instance, imagine a case of communities collecting information on poaching for better monitoring of their local environment. The consequences of community members being caught in the act by poachers could be dramatic, possibly even fatal. Therefore, the equipment should be discreet, easy to carry around and if necessary to hide or discard. Moreover, the true purpose should be obfuscated – in part by restricting access to the data collection software (Vitos et al., 2012, 2013).

On top of that there is the issue of securely storing and distributing data, and taking into account cultural differences and requirements. It was decided at that point that as the projects progress different data protection strategies would be evaluated and ethical approval would be requested. As discussed in section 5.3.5, in the experimentation phase, limited personal data were collected from interested community members such as gender and age, and therefore it was not possible to identify individuals and put them into unnecessary risks.

3.2.5 Summary

This chapter presented the social context, by painting the wider picture of Republic of the Congo and the numerous indigenous communities living in the Congo Basin. Then local issues that threaten the sustainability of the forest on one hand and of the communities on the other such as industrial activities were presented.

Next, this chapter has introduced the technological and social challenges faced by ICT4D initiatives in general, and by this research in particular and presented the social context that this research is carried in. This will help the reader to understand and appreciate the importance and complexities of this research.

Amongst the most important challenges, we identified the literacy levels of participants, along with their technology familiarity, the language barriers, the technological challenges and the security related issues. The challenges were extracted from literature, interviews with area experts and personal observations, and were generalised and grouped so that the outcomes be relevant to similar research in different contexts.

These challenges in combination with the social and environmental issues described in this chapter necessitate the exploration of alternative methods to enable scientifically informed sustainable resource management of the world's tropical forests. In the next chapter we will explore the literature of related work, in order to identify methodologies and recommendations that would drive this research and identify a gap in the literature, which we try to answer in this thesis.

4 Related Work

> *If I have seen further it is only by standing on the shoulders of giants.*
>
> — **Sir Isaac Newton (1642 – 1726)**
> (Physicist, mathematician and astronomer)

In chapter 3, we looked at the wider social context and the issues that local communities face, as well as, the challenges in designing and evaluating ICT systems in that context; now, we can focus on the specific aspect of this work. In this chapter we provide an introduction of related work and the methodological philosophies that underpin this research in our effort to realise the research vision.

The chapter starts with an introduction to ICT4D, an effort to bridge the technological gap in the LICs and improve the local conditions for the citizens (section 4.1). Within ICT4D, we explore the literature for examples of ICT development for illiterate and non-literate user groups (section 4.1.1), and examples of geographical data collection initiatives for non-literates (section 4.1.2).

Afterwards, an introduction to the discipline of HCI is given, which sets the theoretical framework for designing software and mobile systems that are usable and offer satisfaction to the participants (section 4.2). Within HCI, we explore the main goals and principles of HCI (section 4.2.1), the areas of Interaction Design (section 4.2.2), HCI4D (section 4.2.3) and research 'in the wild' (section 4.2.4).

Finally, this chapter explores the differences between ICT4D and HCI4D when it comes to suggestions about UIs for data collection (section 4.3) and a gap in the literature is identified (section 4.5). Given this gap, we explore the areas of audio and physical interfaces (section 4.4) as potential solutions to the usability issues that might arise.

4.1 ICT4D

Information and Communications Technologies for Development (ICT4D) is the use of Information and Communications Technology (ICT) for international development, with a particular focus on poor and marginalised communities (Unwin, 2009). The main idea behind ICT4D, is that the proliferation of ICT infrastructures in a country will lead to further socio-economic development and assist in the improvement of the well-being (Traunmüller and Lenk, 1996; Bhatnagar and Patel, 1998; Heeks, 2009). The area of ICT4D emerged through a series of reports, conferences and funding initiatives that endeavoured to use the emerging technologies to improve the conditions in the LICs (Heeks, 2009). The milestone for ICT4D is the year when the World Bank, along with other agencies, has set up an initiative called InfoDev (Information for Development program) to study how the use of ICTs can assist their efforts to alleviate poverty and promote economic growth in developing regions (The World Bank, 1996).

As a field, ICT4D is very interdisciplinary and draws knowledge and methodologies from a vast number of disciplines and fields such as computer science, information systems, development studies, geography, engineering etc. (Zheng, 2015). As a result, ICT4D systems come in a large variety and support different needs depending on the situation from health (Grover et al., 2009; Sherwani et al., 2009) and agriculture (Plauche et al., 2006; Veeraraghavan et al., 2007; Patel et al., 2010) to education (Wagner et al., 2005) and e-governance (Backus, 2001).

As introduced in section 2.8, various studies that measure the impacts of access to ICTs report that the results are not as expected, with many projects either failing or proving unworkable in the long term (Heeks, 2002; Sey and Fellows, 2009; Heeks, 2010; Rogers, 2011; Barnett, 2012; Doerflinger et al., 2013). For instance, an internal evaluation of the World Bank efforts to promote ICT access and adoption shows that there was a 70% failure amongst the projects (Independent Evaluation Group, 2011).

Although these results could be partially interpreted by the difficulty of discovering and measuring the impact of ICT (Sey and Fellows, 2009), a possible reason for the failure of ICT4D can be the use of inappropriate approaches and technology concepts (Doerflinger et al., 2013). Once again, this highlights the importance of making appropriate use of technology in respect with local conditions and needs. Therefore, this thesis follows an ICT4D approach of problem solving and engineering to explore the applicability of decision trees as effective UIs for non-literate participants to capture geographical data, but it also draws knowledge from disciplines such as HCI and HCI4D in order to design more appropriate tools, conduct appropriate evaluations and improve the usability of ICT tools.

Given that this research aims to explore, within an ICT4D context, the effectiveness of decision trees, it is necessary to conduct a literature review of ICT for illiterate and non-literate users to set up the theoretical framework and identify important research that has been carried out in the area (section 4.1.1). Next, this section explores ICT tools developed in the context of ICT4D that enabled community data collection in LICs (section 4.1.2).

4.1.1 ICT for illiterate and non-literate users

As seen in section 3.2, low or non-literacy continues to be one of the major problems in LICs (see section 1.5 for a definition of LICs). According to United Nations Educational, Scientific and Cultural Organization (UNESCO) in 2008, 796 millions of people around the globe were still unable to read and write despite the several international development and educational efforts, with the vast majority of these living in the LICs (UNESCO, 2010a, 2015). Figure 3.2a on page 37, presents a world map view of literacy levels.

Obviously, the lack of literacy, either in the form of non-literacy or illiteracy (see section 1.5 for the difference), poses a multitude of barriers in the use of modern technology and mobile devices, as most UIs heavily depend on textual and numerical information.

In the context of this thesis, in order to understand the needs and challenges of semi or non-literate people when they interact with technology, especially when they are introduced to it for the first time, a literature review was conducted. The review aimed to identify guidelines, recommendations and principles for designing more effective UIs, and was conducted on research projects concerning UIs for semi and non-literate users, mobile phone applications and ICT solutions for marginalised or poor communities in countries such as India (Parikh et al., 2006; Plauche et al., 2006; Bhamidipaty and Deepak, 2007; Veeraraghavan et al., 2007; Joshi et al., 2008; Agarwal et al., 2009), Pakistan (Sherwani et al., 2007, 2009), South Africa (Blake et al., 2001; Medhi et al., 2009), Philippines (Medhi et al., 2009), Botswana (Grover et al., 2009), Dominican Republic (Shakeel and Best, 2002) and others.

The remainder of the section presents the literature review and it starts by categorising previous work depending on the problem to be resolved (theme of work). Then it moves on presenting the approach that different researchers follow to tackle the issue, along with their development and evaluation methods. Finally, the results of previous work are presented in the last section.

Themes of previous work

Previous work can be categorised in three main themes, depending on the problem researchers are attempting to tackle. A large and growing literature on ICT4D pays particular attention to (a) improving the usability of current mobile or web applications such as the phone book; (b) improving users' access to digital information such as health and agriculture; and (c) providing finance services to users in LICs.

More specifically, in the first identified theme that focuses on studying the usability of current mobile or web interfaces and proposes alternative implementations, one indicative example includes researchers who analyse the usability of the digital phone-book and experiment with different solutions that could alleviate the literacy problem (Chipchase, 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008). Others investigate the navigational abilities of low-literate users by applying cognitive task analysis (Kodagoda et al., 2010) or by comparing the results of novice and experienced web users (Walton et al., 2002). Likewise, Chaudry et al. (2012) investigated different navigational methods (i.e. linear, hierarchical, cross-linked etc.) with low-literate populations in the United States. Finally, Medhi et al. (2010, 2013) has done research on how literacy influences the ability of persons to navigate throughout abstract structures.

The second main theme is focused on examining ways for semi-literate or non-literate users to access digital information. These systems focus on ways for users to access reliable health (Grover et al., 2009; Sherwani et al., 2009) or agriculture information (Plauche et al., 2006; Plauché and Prabaker, 2006; Veeraraghavan et al., 2007; Patel et al., 2010) that could improve their living standards. Likewise, Agarwal et al. (2009) propose an ICT system providing locally relevant information to users such as agriculture info, job adverts and health info. Similarly, Deo et al. (2004) describe the implementation and the usability evaluation of a digital library interface adapted to be used by illiterate users.

Finally, there is a theme that is concerned with the exploration and development of mobile applications for semi or non-literate users to be applied in the finance sector. For instance, Medhi et al. (2009) investigate the usability of current mobile banking applications and alternative interfaces that could be used in the future. Similarly, Parikh et al. (2006) propose a system for capturing micro-finance data using mobile devices.

Approach

The approach and the solution followed by the researchers depends on the theme of study.

In the first theme that focuses on current UIs, the majority of the researchers agree that language and literacy are barriers to the use of technology (Chipchase, 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2009; Chaudry et al., 2012; Kodagoda et al., 2012). For this reason, their approach involves UIs free of textual and numerical information. For instance, 'Rangoli' and 'SymAB' are both initiatives to develop text-free phone-books using colours and icons in the former and symbols in the latter (Bhamidipaty and Deepak, 2007; Joshi et al., 2008). Likewise, Lalji and Good (2008) evaluated the phone-book along with the overall UI design of the mobile phone. Research shows that low literate users tend to favour interfaces with graphics, and many researchers advocate the use of icons (Grisedale et al., 1997; Shakeel and Best, 2002; Ghosh et al., 2003; Parikh et al., 2003; Lewis and Nelson, 2006; Medhi et al., 2006, 2007; Lewis, 2012b; Lewis and Nkuintchua, 2012).

In the examples that endeavour to improve access to information, SDS seem to be the most popular approach. Researchers in this category have perceived the value of voiced-based systems in order to tackle literacy problems (Parikh and Lazowska, 2006; Boyera, 2007) and there is an large number of examples using them (Plauche et al., 2006; Plauché and Prabaker, 2006; Sherwani et al., 2007; Agarwal et al., 2009; Grover et al., 2009; Sherwani et al., 2009; Patel et al., 2010). SDS seem promising, although, other researchers such as Veeraraghavan et al. (2007) developed a system for delivering information to farmers via Short Message Service (SMS) messages. While, Leinonen et al. (2006) tried to develop a solution for providing information to rural communities by a querying through SMS a central database. Obviously, all of these solutions require partial literacy; numerical literacy in the cases of SDS systems where the user has to call a telephone number and follow the instructions or limited reading and writing literacy in the cases of the SMS-based systems.

In the finance examples, Medhi et al. (2009) evaluated the UIs of current mobile banking systems in four countries and identified usability issues. Amongst them, the authors identified the difficulty to navigate using scrolling functions and hierarchical structures, and the difficulty to understand the returned receipts and the associated banking terms such as '*view the last transaction*'. As part of the solution, they suggest text-free interfaces and use of rich-media UIs. On the other hand, Parikh et al. (2006) utilise mobile devices equipped with a camera to interact with paper documents having barcodes and allow users to enter or retrieve micro-finance data (Ghosh et al., 2003; Parikh et al., 2003, 2006).

Development & Evaluation Methodology

As part of their design, development and evaluation, most of the researchers followed a participatory approach or UCD approach (see section 5.2.2). According to the authors, a UCD was preferable because focused on the users, their experiences and their concerns (Preece et al., 2002; Medhi, 2007). This sets a precedent for the advantages of UCD and it acted as a motivation for selecting UCD for this research. In all of the projects in the literature, the researchers initially tried to identify the problem by conducting interviews with the stakeholders (i.e. community members, NGOs etc.), before designing and introducing their solutions.

A prototype was then designed implementing the basic functionalities of the new system and trying to tackle the challenges identified in the first stage. The goal of using prototypes was to provide partial solutions and through their evaluation to redefine the requirements, and further constrain the problem (Carroll, 2001).

The prototypes were then introduced to users for evaluation. For that purpose the researchers followed some typical software development and usability evaluation methods (see section 5.2.3), such as questionnaires and interviews beforehand; observational methods where the researcher is observing the participants using the prototype system and tries to detect difficulties and usability problems; think-aloud techniques where the participants articulate what they think or feel while using the system and finally predefined tasks for the participants to complete and measure their success rates (Gediga et al., 2002).

After the phase of evaluation, the feedback collected by the users along with the observations were used to redefine the requirements and improve the prototype. This process was usually followed more than once until the final system was usable or the evaluation results met the predefined goals for the research team.

Results

Overall, all the researchers agree that language and literacy are obstacles for semi and low-literate users to adopt modern technology. Basic phone functions such as texting, saving a contact to the address-book or navigating through a textual interface pose complexities and are unsuitable for this target group. The design suggestions they advocate include non-textual interfaces with graphics that the users can identify. Likewise, other researchers suggest the use of colours and symbols to create memorable categories for users.

Finally, in the cases of voice-based systems, the researchers suggest that there is a great benefit from the use of voice but there is a need for localisation and adaptation to community requirements. These results are promising and show that low-literate users have no difficulty in dealing with menus of three levels depth.

4.1.2 ICT4D for geographical data collection

When it comes to geographical data collection, as is required for the capture of TEK, digital forms offer more efficient and convenient data collection with fewer errors compared to paper-based surveys (Stanton, 1998; Pundt, 2002; Lefever et al., 2007; Thriemer et al., 2012). Hence, in the context of ICT4D such as environmental management, sustainable livelihood or conservation projects in LICs, mobile data collection platforms running on Personal Digital Assistants (PDAs) or mobile phones are gaining popularity. Platforms like ODK (Anokwa et al., 2009; Hartung et al., 2010) and EpiCollect (Aanensen et al., 2009), use mobile phones and smartphones to facilitate form-based data collection, where forms are uploaded in a centralised database, and offer tools to visualise and analyse the results. The popularity of digital collection in LICs can be reflected by the myriad of projects that collect information from health (Anokwa et al., 2012; Rajput et al., 2012; Miller et al., 2014; Underwood et al., 3013), to tracking water access (Chaudhri et al., 2012; Champanis and Rivett, 2012; Hartung, 2012, p. 62) and to household surveys (Kateera et al., 2015; Rey-Moreno et al., 2016; Hammond et al., 2017). In addition, in PLA and PGIS initiatives, participatory mapping is a very common methodology for researchers to obtain local knowledge and it is used in many projects in LICs (Chambers, 1994; Peluso, 1995; Abbot et al., 1998; Corbett et al., 2006).

Although such platforms are heavily used in an ICT4D context, they were initially designed for use in western scenarios with literate users in mind and their interfaces heavily depend on textual interactions (Aanensen et al., 2009; Open Data Kit, 2015b). As a result, in all the above-mentioned examples, the process of collecting the data and importing it into the digital tools is performed by people who are literate and tech savvy to operate the data collection software, or by expert cartographers with the communities' active assistance.

However, there are a few examples in the ICT4D literature, where mobile devices were handed to semi or non-literate participants in order to record observations. In this section, we turn our attention to examples that employ ICTs for allowing participants in LICs to collect geographical type of data. We start with Cybartracker and we continue with the example of Helveta.

CyberTracker

CyberTracker (Cybertracker, 2015) is one of the very first geographical data collection platforms developed in 1997 that targeted hand-held computers or PDAs (Lane et al., 2010) and was designed for semi-literate animal trackers to record observations (Spinney, 1998; Hartung et al., 2010). In terms of UI, CyberTracker relies on interfaces were text and icons allow semi-literate users to record a variety of important data (figure 4.1) (World Bank, 2017). For instance, Liebenberg et al. (1999) describes the use of the tool by illiterate trackers in South Africa to record the Rhino patterns and habits. In that, the trackers were using the tool to answer questions by following a sequence of icon-based screens (Liebenberg et al., 1999, 2017). Similarly, Mayes (2002) describes the use of CyberTracker by trackers in Caprivi, Namibia to monitor the wildlife in the national park. Likewise, Liebenberg (2011), describes how CyberTracker was used by community members in the Western Kgalagadi, in Botswana, to collect animal tracks.

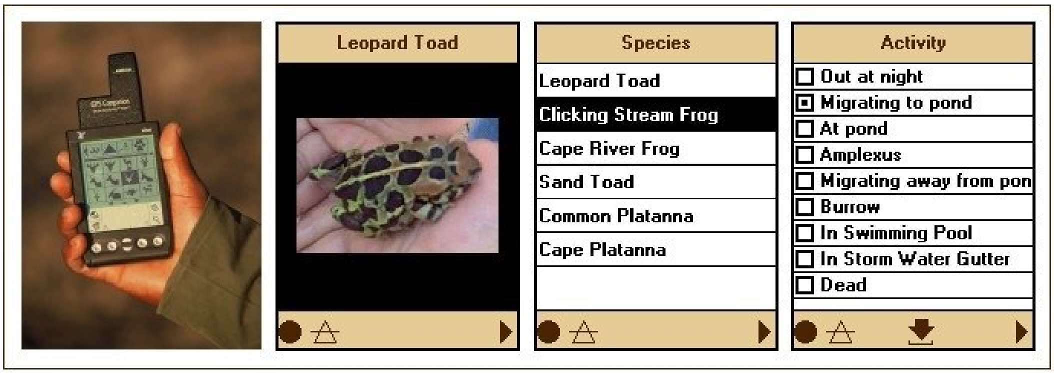


Figure 4.1.: CyberTracker's User Interface. *Source: Cybertracker (2015).*

CyberTracker later evolved into a generic data collection tool used in other conservation projects (Parr et al., 2002; Douman, 2006; Ansell and Koenig, 2011; Ens, 2012). Nowadays it is outdated, primarily because it relies on expensive and equally outdated PDA devices that lack the processing power and built-in sensors of today's smartphones. Currently there is an effort underway to port CyberTracker to Android and recently there has been released a beta version (Cybertracker, 2015). However, this version, which is ported from Windows Mobile to Android, does not take full advantage of modern Android features. Also the ported UI was initially designed for low-resolution PDA screens and does not look optimal on modern devices (figure 4.1).

Helveta

In a similar vein, Lewis (Lewis, 2012b) describes the collaboration between a forest tribe and the logging company to provide the community with PDA devices running bespoke software with an interface consisting of pictorial icons, to record the locations of important resources. The first case study took place in the RoC, where in 2005 one of the local logging companies, CIB, decided to gain Forest Stewardship Council (FSC) certification (FSC, 2015). This would certify the company as environmentally and socially sustainable in their forestry operations. Part of the certification required them to respect the rights and resources of indigenous and local forest people (Lewis, 2012b).

However, due to cultural and literacy issues there were major communication challenges between the logging company and the local forest communities regarding the mapping of local resources that were valuable for the communities' livelihood (Lewis, 2012b).

A solution was developed by a consortium (Lewis and Nelson, 2006) that introduced the Mbendjele, a Pygmy group living in the Republic of the Congo, to the use of rugged, hand-held PDA devices, paired with external, portable GPS receivers and bespoke software, developed by Helveta[1], that allowed non-literate participants to record observations using a pictorial decision tree (Lewis, 2012b; Lewis and Nkuintchua, 2012) (figure 4.2).

At this point, it is necessary to clarify what a 'decision tree' is, which can be defined as a type of diagram that represents a question which the participant has to reply and is a structure in which the leaves represent classifications or answers to the question, while the in-between nodes represent categories or groups that lead to these classifications. For instance, figure 4.3 shows a minimal decision tree which asks the user to provide his preferable mode of transport. The available choices are *Car*, *Bike*, *Bus* and *Tube*, while *Private* and *Public* modes of transport are classifications that lead to the answer. Users can navigate the decision space by repeatedly selecting a child node until they reach a leaf node, which represents a final selected value.

The key resources they documented as valuable to them were then verified and removed from the cutting schedule of the timber company. The data was presented as a map that some of those involved in the geographical data collection began to learn to understand. The Mbendjele most closely involved with the process started to appreciate the power of maps when they witnessed the seriousness with which

[1]Helveta Ltd, currently renamed to Elements Software, is a UK-based software company developing supply-chain management applications for food and timber.

(a) Younger men explaining how the device works to an elder. **(b)** Close up photo of the PDA and the custom software.

Figure 4.2.: Examples of the hand-held PDA system. © *Jerome Lewis, ExCiteS group*

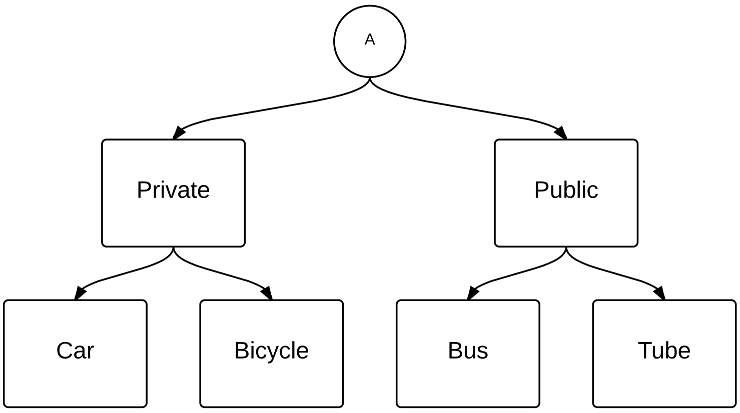


Figure 4.3.: Example of a simple decision tree about transport modes.

the timber company treated them and their effectiveness in communicating vitally important information about their key resources across a cultural boundary, from non-literate hunter-gatherers to university-educated expatriate company managers, something that had seemed insurmountable to them just a year or so earlier (Lewis, 2012b).

In 2007 a similar initiative was set up in the forest of eastern Cameroon, where numerous indigenous Baka pygmies are living (Hopkin, 2007; Lewis, 2012b; Lewis and Nkuintchua, 2012). The aim of the project was to introduce communities to participatory mapping and support them to monitor resources use, document their territories and share their results with local stakeholders (Lewis and Nkuintchua, 2012).

As explained in section 2.6, participatory mapping was already a tool in PLA and PGIS initiatives as an approach of obtaining knowledge from local communities concerning their living conditions and their environment (see section 2.6). However, the key difference in Lewis' approach was the use of ICT technologies that could be used by the communities themselves, whereas in traditional PGIS exercises in this context, the documenting of resources and map-making was produced by expert cartographers with the communities' active assistance.

Conclusion

Nowadays both platforms (CyberTracker and Helveta) are outdated, primarily because they relied on expensive and equally outdated devices that lack the processing power and built-in sensors of today's smartphones.

Nevertheless, both examples suggest that pictorial decision trees are appropriate and effective as a classification tool and UI for non-literate participants. As explained, in these, the structure of a 'decision tree' is a type of diagram that represents a question which the participant has to answer. The leaves of the structure represent the final answers to the question, while the in-between nodes represent categories or groups that lead to the answers.

4.2 Human-Computer Interaction (HCI)

Human-Computer Interaction (HCI) is an interdisciplinary academic field focused on the study, planning and design of the interaction between people and computers. Historically, it emerged in the early 1980s and initially was a combination of computer science, cognitive science and human factors engineering (Carroll, 2013). However, it evolved and nowadays it is considered as an intersection of areas such as computer science, psychology, sociology, cognitive science, anthropology, artificial intelligence, engineering and so forth (Shneiderman and Plaisant, 2004). According to the Association for Computing Machinery (ACM), HCI is defined as:

> *Human-computer interaction is a discipline concerned with the design, evaluation and implementation of interactive computing systems for human use and with the study of major phenomena surrounding them (ACM SIGCHI, 1992)*

In the following sections, we introduce the HCI goals and principles (section 4.2.1), as a set of tools and guidelines that lead to more usable and appropriate products when followed. Next, we introduce the discipline of interaction design, an area of HCI that is concerned with the design of interactive digital products and systems that could provide us with design approaches, patterns and guidelines to tackle common interaction issues, which can be applied when designing ICT tools for non-literate or illiterate participants (section 4.2.2). Finally, we explore the areas of HCI4D and research 'in the wild' (sections 4.2.3 and 4.2.4 respectively).

4.2.1 HCI Goals and Usability Principles

HCI Goals

The goal of HCI is to examine the relationship between users and computers, and make the latter more usable and appropriate for the user's needs (Sellen et al., 2009). Research indicates that perceived usefulness and ease-of-use play the leading role in the acceptance of a technology (Davis, 1989; Bagozzi et al., 1992). Therefore, technologies developed in accordance with HCI principles are more likely to be adopted by the end users.

According to Preece et al. (2002) in '*Interaction Design*', the design goals of HCI are:

- **Effectiveness**: Measures how effective is a product to use. Also it checks if a system in doing what it is supposed to do.
- **Efficiency**: Measures how efficient is a product to use, and in what extend it supports users in completing their tasks.
- **Safety**: Measures how safe is a system in protecting a user from undesirable situations.
- **Utility**: Measures the extent to which a system provides useful functionalities to the user.
- **Learnability**: Measures how easy is for a user to learn how to operate the system.
- **Memorability**: Measures how easy is for a user to remember how to operate the system after the phase of training.

HCI Usability Principles

HCI is a very diverse field and as such there are many theories and principles for the development of usable UIs and for their evaluation (Nielsen, 1993; Shneiderman and Plaisant, 2004). As a result, there have been many efforts to reduce the complexity and create a common set of rules (Nielsen, 1993; Baker et al., 2002).

Nielsen in his attempt to categorize the most common principles came up with a list of ten '*heuristics*' rules that work as recommendations for UI designers (Nielsen, 1993, 1995):

1. **Visibility of system status:** The users should always be informed on what is happening via timely and appropriate feedback.

2. **Match between system and the real world:** The user should be informed with the use of concepts and terms that are familiar to him, instead of system-oriented terminology.

3. **User control and freedom:** The system should support easy to use undo and redo functionalities that allow the user to escape from a situation he ended up by mistake.

4. **Consistency and standards:** The application should follow the platform conventions and have consistent results for the same actions.

5. **Error prevention:** A careful design can eliminate the errors, rather than informing the user with error dialogs.

6. **Recognition rather than recall:** The user's memory load should be minimized by always showing all the available options and providing sufficient help throughout all the steps.

7. **Flexibility and efficiency of use:** The system should allow users to customize their experience so that it is appropriate for both inexperienced and experienced users.

8. **Aesthetic and minimalist design:** The system should not provide excess or irrelevant information via dialogues and menus.

9. **Help users recognize, diagnose, and recover from errors:** The system should provide clear and understandable error messages without code er-

rors and system language. In addition, the messages should also provide a solution for the user to recover the system.

10. **Help and documentation:** The system should provide easy to access and search help and documentation. The documentation should not be verbose and explain in simple steps what actions the user has to follow.

Similarly, Dix et al. (2003) in '*Human-Computer Interaction*' suggest the following principles of usability design:

1. **Learnability:** Indicating the ease of new participants to effectively learn how to ease the system.

2. **Flexibility:** Indicating the multiplicity of ways to interact with the system.

3. **Robustness:** Showing the level of support provided to the user for error handling.

In the context of this research, HCI can provide the theoretical framework for developing more usable and intuitive interactions by trying to achieve the HCI goals described in the previous section. In addition, HCI principles described above can lead to the design of software and mobile applications that are easy to learn, flexible and robust.

4.2.2 Interaction Design

Interaction Design (IxD) is an area of HCI dealing with the design of interactive digital products, systems and services (Cooper et al., 2007). According to Lowgren (2013), '*Interaction design is about shaping digital things for people's use*'. It borrows theories and principles from areas such as the traditional design and engineering; however, the main focus is on behaviour, e.g. how products work, and on how to satisfy the needs of the users who interact with the product or the service (Cooper et al., 2007).

According to Saffer (2009), Interaction Design focuses on users and how they can better achieve their goals; finds alternative and appropriate solutions to the interaction problems and uses prototyping and modelling to test the suggested solutions.

Interaction Design Approaches

In the area of interaction design, there are four dominant approaches that designers could follow in order to tackle interaction obstacles: User-Centred Design (UCD), Activity-Centred Design (ACD), Systems Design and Genius Design (Saffer, 2009).

As we will further explore in section 5.2.2, UCD approach's central idea is that the best designed products or services derive from understanding the needs of the people who will use them. This approach focuses on user needs, wants and goals, while the designer's role is to capture and transform these needs into useful interfaces (Preece et al., 2002; W3C, 2004; Medhi, 2007; Saffer, 2009; IBM Design, 2013). In this approach, users are involved in every stage of the development, ideally from the beginning of a project, to provide insights that drive the design decisions being made. In addition, users are consulted to evaluate the suggested solutions according to the degree they satisfy their needs and goals (Saffer, 2009).

In the Activity-Centred Design (ACD) approach, the focus is on the tasks and activities that have to be accomplished rather than the goals of the user (Norman, 2005, 2006; Saffer, 2009). According to Saffer (2009) activities are defined as a set of decisions and actions that are executed to achieve a certain purpose and can vary from short and simple to time consuming and complicated. Activity-Centred Design (ACD) has its theoretical roots in Activity Theory (Norman, 2005; Saffer, 2009), in which activities are described as actions users do in order to reach a goal (Kaptelinin and Nardi, 1997). The main difference compared to UCD is that users are advocated or observed in order to study their behaviour with the system, rather than finding their goals and motivations (Saffer, 2009).

In the Systems Design approach, the focus is on the system to be designed and its components. While UCD focuses on the users and their needs, in this approach the whole system is the centre of the design process offering a holistic view of the project (Saffer, 2009). In addition, systems design offers a more structured approach that could be proved more appropriate for complex problems (Saffer, 2009).

As a system, Saffer (2009) defines not only computer structures but also combinations of people, devices and objects that can interact with each other. The complexity of systems can vary from simple to highly complex ones.

Finally, in the Genius Design approach, the designer or the team of designers is solely responsible for taking the design decisions based on their skills, experience and wisdom (Saffer, 2009). The designer decides based on his knowledge of what the users need and what is the best solution for them, then users are employed, but only at the end of the design procedure, to evaluate and test the product (Saffer, 2009). Usually, the driver for using the genius approach, is lack of resources to include users in the design process or privacy reasons (Saffer, 2009).

In our case, designing appropriate technological means for communities to participate in geographical data collection, the most suitable interaction design approach is the UCD that can be used to facilitate the development of software meeting the needs of users. This decision is also informed by the literature in ICT4D, where many reseachers advocate for the use of UCD (section 4.1). In chapter 5, the participatory approach we followed is presented in more detail.

4.2.3 HCI4D

While HCI and Interaction Design provide all the necessary guidelines, recommendations and principles for designing more effective UIs, as we seen in the previous sections, these do not naturally apply to the context of LICs. Therefore, in the last two decades, there is an increased interest in HCI4D, a sub-area of HCI that examines how to better design and evaluate ICTs in LICs, taking into account local cultural and social differences (Ho et al., 2009; Wyche, 2011) and the challenging infrastructural contexts (Ho et al., 2009).

According to Dearden et al. (2007), the key issues that HCI4D explores and tries to address are:

- **Interaction Metaphors**: Exploring how the metaphors employed in western scenarios such as Windows, Icons, Menus and Pointers (WIMP) can be used in the context of LICs.

- **User Analysis**: Better understand the users, their contexts and requirements by understanding the their social and cultural differences.

- **Interaction Methods**: Localization and customization / alternatives to traditional input output methods.

- **Evaluation Methods**: Exploring more appropriate methods to test and evaluate ICTs to receive more accurate feedback.

As in ICT4D, HCI4D spans into different areas and cover systems in agriculture (Gandhi et al., 2007; Parikh et al., 2007; Veeraraghavan et al., 2007), education (Kam et al., 2007; Furtado et al., 2008; Moraveji et al., 2008), healthcare (Braa et al., 2004; DeRenzi et al., 2008; Luk et al., 2008), finance (Parikh et al., 2006; Medhi et al., 2009) and others (Javid and Parikh, 2006; Sharma et al., 2007).

Similarly to the ICT4D literature, the majority of the literature in HCI4D seems to apply UCD or a participatory design approach for the design and evaluation of the technological artefacts (Braa et al., 2004; Merkel et al., 2004; Puri et al., 2004; Elovaara et al., 2006; Gandhi et al., 2007). This once again sets a precedent for the advantages of UCD and justifies the use of UCD in this thesis.

4.2.4 HCI research 'in the wild'

Lately, there has been a paradigm shift in how usability evaluations are designed and conducted. Typically, evaluations were conducted in the isolated and restricted environment of labs, were users were focused on performing particular tasks and other distractions were minimised (Rogers, 2011).

However, researchers in the field of HCI are abandoning their labs in favour of carrying out their evaluations in the physical setting of their users (Brown et al., 2011; Rogers, 2011; Chamberlain et al., 2012). This phenomenon of field evaluations or field trials is commonly referred to as '*in the wild*' research. However, this comes with a plethora of challenges. For instance, in the wild evaluations are costly, take considerably more time and are very labour-intensive (Davies, 2005; Kjeldskov and Skov, 2014). Although in the wild research presents these challenges, it can also identify issues that are impossible to uncover on lab settings by providing a better contextual understanding to researchers (Rogers et al., 2007; Reitmaier et al., 2010).

4.3 ICT4D vs HCI4D

As explained in section 4.1.2, the success of platforms such as CyberTracker and Helveta in providing semi or non-literate participants with ICT tools in order to record observations, suggests that pictorial decision trees are appropriate and effective as UIs for TEK data collection. Additionally, research conducted with low-literacy populations suggests that decision trees can be useful for navigation but should not exceed **five** levels (Chaudry et al., 2012).

On the other hand, recent studies in HCI4D point out that because low literacy levels are usually the result of a lack of formal education, such people may also struggle with cognitive abilities besides reading and writing (Katre, 2006; Linden and Cremers, 2008; Brown et al., 2012; Medhi et al., 2013). In studies involving illiterate people in India, Medhi et al. (2013) found that underdevelopment of skills such as conceptual abstraction and categorisation may explain why non-literate users perform worse than literate users when navigating UIs even when they are text-free (Medhi et al., 2010; Medhi et al., 2010; Medhi et al., 2012; Medhi et al., 2013). Brown et al. (2012), suggest that decision trees (and hierarchical menu structures) in combination with abstract icons are too complex for illiterate people and pose a major challenge. Prasad et al. suggest that differences in mental models, due to cultural differences, prevented non-literate users in rural India from understanding abstract concepts such as the 'postcard' metaphor, where the service of email is analogised with a postcard being sent by post (Prasad et al., 2008). Finally, Walton et al., in studies in South Africa, discovered usability difficulties when users were presented with hierarchical information structures (Walton et al., 2002).

Additionally, over the past century, a significant increase on human performance on IQ tests was revealed in different parts of the world (Flynn, 2009). This phenomenon is named the '*Flynn effect*' after James Flynn who had an essential contribution to recognising, studying and measuring it (Flynn, 2009). Amongst the proposed causes, Flynn suggests that the increase is not an actual increase in intelligence rather than an increase in abstract problem solving (Flynn, 1987), which could be partially explained by improvements in education (Neisser, 1997; Marks, 2010). This once again suggests that skills such conceptual abstraction and categorisation are the result of education and might not be present in non-literate communities.

In summary, there seems to be a contradiction in the literature and uncertainty whether decision trees are an appropriate solution for interfaces to gather TEK.

4.4 Audio and physical interfaces

As there is still much uncertainty regarding the effectiveness of decision trees as UIs for data collection with non-literate communities in ICT4D contexts, it is essential to explore alternative methods for enhancing the usability of decision trees. Research has shown that providing information across different human senses can have an impact on a participant's performance (Brewster et al., 1993; Lim et al., 2013). In this section we explore the use of audio and physical interfaces to improve participant's performance.

Audio interfaces

Previous studies in HCI suggest the use of 'earcons' or 'auditory icons' when designing interfaces for smaller displays or for users with visual impairments (Walker et al., 2006, 2013). Earcons (or auditory icons) are audio cues that can be used in UIs to provide information or feedback to the user (Sumikawa, 1985; McGookin and Brewster, 2004). These cues can be synthetic or natural sounds in the case of earcons, and speech for auditory icons (McGookin and Brewster, 2004). Several studies had been conducted to evaluate audio cues in UIs and they show that the use of auditory icons has a positive impact on factors such as learnability, memorability and performance (Edworthy and Hards, 1999; Ulfvengren, 2003; Bonebright and Nees, 2007; Garzonis et al., 2009a,b). As a result, auditory cues (mainly in the form of notifications) have been employed in the context of cognitively demanding systems such as power plants (Thunberg and Osvalder, 2009) and airplane cockpits (Patterson and Mayfield, 1990; Ulfvengren, 2003). Although it goes beyond the scope of this thesis to further analyse the cognitive effect of audio when employed on UIs, there is evidence that the use of additional sources of information (for example augmenting a UI with more modalities such as audio) can reduce the 'cognitive load'[2] on participants (Jeung et al., 1997; Menelas et al., 2010; Lim et al., 2013). Hence, this could explain the better results that are reported throughout the literature.

In ICT4D projects, audio clips recorded in the local language have been employed by researchers to assist rural users in India to perform micro-finance transactions (Parikh and Lazowska, 2006; Parikh et al., 2006). Similarly, Medhi et al. (2006) used audio clips in applications targeting low-literate users to access job seeking information and map navigation clues on a digital map. Other examples of audio recordings used in ICT4D projects, include the use of SDS where the user has to call a telephone number and follow the instructions to get access to the provided information (Plauche et al., 2006; Plauché and Prabaker, 2006; Sherwani et al., 2007; Agarwal et al., 2009; Grover et al., 2009; Sherwani et al., 2009; Patel et al., 2010).

As seen in the above ICT4D scenarios, audio and SDS have shown promising results and therefore it would be interesting, in situations were decision trees deemed inadequate, to be used by non-literate participants to augment the decision trees with audio cues that would reduce the cognitive load on participants and potentially increase their abstract problem solving.

[2] Cognitive load is a term used in cognitive psychology to express the total mental effort being used to perform a task (Sweller, 1988).

Physical interfaces

Recently there has been a growing interest in forms of interaction that combine physical objects and graphical interfaces (Fitzmaurice et al., 1995; Ishii and Ullmer, 1997; Shaer, 2009; Jensen et al., 2012; Dijk et al., 2015; Zhou, 2015), usually referred as TUIs. Providing a link with the real world and building on users' knowledge on how to interact with physical objects can improve participants' confidence (Rekimoto et al., 2001). Although the use of TUIs in practical applications is still in its infancy, literature suggests that TUIs feel more natural to users due to the notion of 'affordance', which suggests that users have more possibilities for action in a given situation (Shaer, 2009), and 'embodied cognition'[3] (Dourish, 2004; Hornecker and Buur, 2006; Antle, 2007; Fernaeus et al., 2008; Hornecker et al., 2008; Shaer, 2009; Zhou, 2015). Again, it is out of scope for this thesis to explore the literature on cognitive science and further analyse the effect of TUIs on participants.

In terms of ICT4D and HCI4D, there are very limited examples of physical interfaces being used to provide non-literate users with interfaces for communicating with digital technology. Parmar et al. (2009) discusses the use of TUIs as a mechanism to access health information and reports promising results. In a similar vein, Unnikrishnan et al. (2016) describe a tangible game for teaching underprivileged children in rural India and reports promising results.

Once again, in situations were decision trees deemed inadequate, it would be interesting to <u>explore whether TUIs can facilitate data collection and improve data collection due to the increased affordances and embodied cognition</u>. Hence, this thesis will endeavour to investigate how physical interfaces can be linked with data collection projects.

4.5 Research Gap

As we seen in section 4.2, usability i.e. perceived usefulness and ease-of-use, and satisfaction play the leading role in the acceptance and adoption of a technology (Davis, 1989; Bagozzi et al., 1992). In the case of collaborative data collection, the lack of usability of an ICT solution can negatively influence the validity of the collected data and thus impact the success of an environmental monitoring project.

[3]Embodied cognition is a theory of cognitive science that a human's brain is not the only resource that defines behaviour. On the contrary, the brain interacts with the nervous system in the body to generate behaviour (Thompson, 2012). As Wilson and Golonka simply explain, 'states of the body modify states of the mind' (Wilson and Golonka, 2013).

However, as we explored above, there seems to be a gap and contradiction between ICT4D and HCI4D in regards to the UI and especially to the appropriateness of decision trees; an example of this is the lack of research into the usability of pictorial decision trees. On the one hand, ICT4D practitioners and researchers report success stories from the field (Liebenberg et al., 1999; Mayes, 2002; Lewis and Nelson, 2006; Lewis, 2007; Liebenberg, 2011; Chaudry et al., 2012; Lewis, 2012b; Cybertracker, 2015; Liebenberg et al., 2017), while on the other, HCI4D researchers support the argument that due to the abstract nature of decision trees, they are not applicable for non-literate user groups (Walton et al., 2002; Katre, 2006; Linden and Cremers, 2008; Prasad et al., 2008; Medhi et al., 2010; Medhi et al., 2010; Brown et al., 2012; Medhi et al., 2012; Medhi et al., 2013). As introduced in the next chapter, this gap motivates our research agenda as this research aims to explore the advantages and limitations of decision trees when employed as user interfaces on mobile devices to permit non-literate forest people to capture environmental data.

4.6 Summary

In this chapter the literature to identify related work when it comes to designing and evaluating ICT tools for semi or non-literate participants to collect geographical information was explored. The chapter started by exploring the area of ICT4D that attempts to bridge the technological gap in LICs (section 4.1) and provide this research with relative examples of ICTs for data gathering. Next, the discipline of HCI was analysed with a focus on HCI4D, that provides us with methodologies and guidelines on designing more effective UIs (section 4.2). Finally, the difference approach and contradiction between ICT4D and HCI4D regarding pictorial decision trees when it comes to geographical data collection by non-literate communities was described (section 4.3). This contradiction between the two disciplines provides us with the opportunity to explore the advantages and limitations of decision trees and motivates our research questions and agenda.

5 Overall Methodology

> *You don't have to be a genius or a visionary or even a college graduate to be successful. You just need a framework and a dream.*
>
> — **Michael Dell**
> (Founder and CEO of Dell Inc.)

This chapter provides an introduction to the methodological approach that underpins this research. It opens with restating the research questions of the thesis (section 5.1), and then it outlines the methodological approaches of AR (section 5.2.1), UCD (section 5.2.2), as well as the Usability Engineering methods for evaluating ICT systems (section 5.2.3). It then concludes with the methods applied in this research to introduce, evaluate and adapt ICT systems with communities having little or no formal education or prior exposure to technology, and whose sociocultural background and understanding may differ wildly from those within which such systems are usually designed (section 5.2.4).

In previous chapters, we explored how the twin forces of economic development and global commodity markets have a direct impact on the livelihoods of local communities by causing ever larger parts of the rainforest to be opened up to industrial-scale resource extraction and agricultural activities. In this chapter, we move to the collaborations with communities to develop ICT systems for them to collect their vast environmental knowledge by introducing the case studies of the thesis (section 5.3). Within that context, this research had the unique opportunity to explore the two research questions as defined in the previous chapter. Finally, this chapter clarifies the personal contribution of the author per case study (section 5.3.4), since this research was part of an interdisciplinary research group.

5.1 Research questions

As seen in the previous chapters, there is a growing imperative to record and protect TEK, as it is recognised as a promising solution to achieve long-term and sustainable management of ecosystems (Berkes, 2012; Ehrlich and Ehrlich, 2012; Jensen et al., 2012; Bonney et al., 2014). Local and indigenous communities around the world, possess a rare and complex understanding of their territory and the wider vision for this research is to provide the technological means to support them to share and apply their TEK and their knowledge of local environmental conditions using scientifically accepted methods that could lead to improvements in environmental governance and social-environmental justice (West et al., 2006; Raftree and Nkie, 2011; Lewis, 2012b). Thus, the general research agenda that is driving this research is:

> *How can ICT be applied to enable the collection of TEK to increase environmental sustainability?*

As we seen in section 4.2, usability i.e. perceived usefulness and ease-of-use, and satisfaction play the leading role in the acceptance and adoption of a technology (Davis, 1989; Bagozzi et al., 1992). In the case of collaborative data collection, the lack of usability of an ICT solution can negatively influence the validity of the collected data and thus impact the success of an environmental monitoring project. Therefore, in the wider area of sustainability and data collection of TEK, we narrow our research focus on the usability of the suggested ICT tools to gather TEK. For that reason, a literature review was conducted in the areas of ICT4D and HCI4D to explore suggestions and solutions regarding the design and evaluation of data collection tools with communities that are not familiar with technology (see chapter 4).

However, as explored in chapter 4, there seems to be a gap and contradiction between ICT4D and HCI4D in regards to the UI and especially to the appropriateness of decision trees. On the one hand, ICT4D practitioners and researchers report success stories from the field, while on the other, HCI4D researchers support the argument that due to the abstract nature of decision trees, they are not applicable for non-literate user groups (see section 4.5). This research aims to explore the advantages and limitations of decision trees when employed as user interfaces on mobile devices to permit non-literate forest people to capture environmental data. It will do this by focussing on three aspects of the problem:

- The appropriateness of decision trees and their abstraction and complexity (see section 4.5);
- The use of other sensory information to support decision trees such as audio interfaces (see section 4.4);
- The use of physical objects to support data capture for TEK (see section 4.4).

Therefore, more formally, the Research Question (RQ) of this thesis is:

RQ 1 **Are pictorial decision trees an appropriate interaction style for non-literate communities in Central Africa to capture TEK?**

Additionally, as will be presented in section 5.2.2, methodologies that are very popular in the discipline of HCI such as UCD and although that they are regularly employed in HCI4D scenarios (Roman and Colle, 2002; Colle, 2005; Medhi, 2007; Gruijters and Blake, 2008; Lalji and Good, 2008; Devezas et al., 2014), they come with known difficulties. The lack of literacy and lack of computer skills amongst the participants, presents communication issues since participants cannot express requirements, goals and functionalities in terms of ICT systems (Teka et al., 2016). In addition, researchers argue that users in ICT4D projects usually lack the experience to comment or suggest alterations, or to contribute in participatory exercises (Winschiers, 2006; Chetty and Chetty, 2007; Chetty and Grinter, 2007; Winschiers-Theophilus, 2009; Rodil et al., 2012). Hence, this research provides an ideal opportunity to reflect on the process of designing and evaluating ICT tools with decision trees and make an additional contribution to science. As a result, to address the above research question RQ 1, this thesis will also explore and attempt to answer the following sub-question:

RQ 2 **What are the challenges in designing a system that incorporates pictorial decision trees for non-literate people living in Central Africa to capture TEK?**

5.2 Methodological approach

Before we explain the methodologies employed to explore whether decision trees can be employed for geographical data collection in Central Africa, it is necessary to explain the research context that this thesis was conducted in, and the methodological outline that this individual research followed. This will help the reader to understand the context, but also the constrains and the scope of this work.

Research context Given the scale of the issue of sustainable development and the inadequacy of existing paradigms it is clear that there is a need for interdisciplinary approaches to tackle the issue. Therefore, in 2011, the research group ExCiteS was jointly founded, when Professor Muki Haklay, Dept. of Civil, Environmental & Geomatic Engineering (CEGE), and Dr Jerome Lewis (Dept. of Anthropology) secured a five-year grant from the Engineering and Physical Sciences Research Council (EPSRC: EP/I025278/1) to engage with citizens in a bottom-up approach of identifying issues that affect them, through participatory action research to develop and implement sustainable solutions. Lewis has known and collaborated with the Mbendjele, one of the local forest communities inhabiting the forest of Congo Basin, since 1994. His applied research on supporting forest peoples' conservation efforts makes him a world expert on issues of discrimination, economic and legal marginalisation and human rights abuses. Hence, the funding and the expertise of Lewis in the Congo Basin area, enabled the group to closely collaborate with intermediaries, stakeholders and communities in the RoC.

As a result, this research has been conducted as part of work carried by the ExCiteS research group that is composed of computer scientists with strong interest in HCI, anthropologists and geographers – aiming to enable and study the participation of lay people in citizen science activities in general, and participatory environmental monitoring and mapping in particular. The group's primary focus is on indigenous communities living in remote and *extreme* environments such as tropical rainforests (Stevens et al., 2014). Following an *Action Research (AR)* approach, ExCiteS operates in collaborations with forest communities and local intermediaries such as NGOs, logging companies and national parks. While the details of each project differ, the common goal is to enable communities to conduct environmental monitoring or mapping using digital technology, with the purpose of asserting their rights, managing responses to changing ecological conditions, or facilitating communication and information sharing with outsiders. The intermediaries enable the researchers of the group to work with otherwise difficult to reach communities and often act as the eventual coordinators of the project. Hence, they bring their own requirements and expectations, and in some cases may be considered as 'clients'. Consequently, our role in these multi-stakeholder projects is multifaceted. We act as community facilitators, logistics planners, interface designers, software engineers, and ICT consultants. In addition, we are aiming to create generalised methodologies and reusable tools which can be applied across a wide range of projects, including those beyond our own.

Methodological outline Within ExCiteS, an AR approach was followed for collaborating with different indigenous communities and stakeholders. AR was employed due to its democratic nature and the active involvement of communities in the problem definition and resolution (see section 5.2.1).

From a methodological standpoint, this individual research, conducted within ExCiteS, is mostly related to the fields of ICT4D as the primary question to be explored is whether decision trees 'work'. Therefore, it follows an engineering approach of problem solving and employs usability engineering methods to evaluate the solutions. It does however differ from typical empirical user studies of usability engineering, due to the difficulties in conducting highly controlled lab evaluations as this work was conducted 'in the wild' (see section 4.2.4). Thus, the applied methodology borrows principles of AR, and UCD which use systematic observation and data collection methods focused on real world problems and situations. Typically UCD is characterised by multiple experimental iterations with the end users. However, in the case studies of this research, access to participants was restricted by a series of challenges: distance, costs and logistics for organising a field trip and getting in contact with participants; stakeholder expectations which do not always match with our research priorities; cultural barriers; and time constraints.

In the following section, the areas of AR (section 5.2.1), UCD (section 5.2.2) and Usability Engineering (section 5.2.3) are reviewed, while in the final section, the methodologies employed in this thesis are presented (section 5.2.4).

5.2.1 Action Research

Action Research is an approach to knowledge and inquiry that aims to link practice, ideas and research for promoting human and environmental development (Reason and Bradbury, 2008, p. 1). Reason and Bradbury draw on an extensive range of sources to conclude that AR is not a '*methodology*', but an '*orientation to inquiry*' that seeks to resolve important practical issues within a community or organisation and leads to positive change on small or great scale. In addition, the authors provide a comprehensive and thorough definition regarding AR, focusing on the social change that it can facilitate:

> *Action Research is a participatory process concerned with developing practical knowing in the pursuit of worthwhile human purposes. It seeks to bring together action and reflection, theory and practice, in participation with others, in the pursuit of practical solutions to issues of pressing concern to people, and more generally, the flourishing of individual persons and their communities (Reason and Bradbury, 2008, p. 4).*

According to Reason, AR is two-faceted, having a philosophical and political side on one hand and a practical on the other (Reason, 2015). The philosophical and political dimension of AR is focusing on creating philosophically sound and pragmatic knowledge, while the practical side is focusing on creating practical knowledge that improves personal and professional life (Reason, 2015). In the scope of this thesis, AR was employed by the research group as a means of generating practical knowledge in collaboration with local communities to enable their participation in environmental monitoring schemes that allows them to protect and sustainably manage their local resources.

Historically, AR stems from the work of Kurt Lewin (1890–1947) and the series of socio-technical experiments he conducted to solve social problems and assist organisational change, working on the topics of inter-group relations, eating habits and prejudice (Greenwood, 2006; Stebbins et al., 2009), and the work of researchers in the Tavistock Institute, based in London, to treat psychological disorders on soldiers after the second world war (Kock, 2015). Lewin's defined AR as '*a comparative research on the conditions and effects of various forms of social action and research leading to social action*' and he suggested a process that includes '*a spiral of steps, each of which is composed of a circle of planning, action, and fact-finding about the result of the action*' (Lewin, 1948, p. 203). Although AR has significantly evolved since Lewin's inception, the process that the researcher goes through still consists of a spiral with four major phases '*planning, acting, observing and reflecting*' (Zuber-Skenitt, 1993, p. 46), that are presented in figure 5.1. AR is a four-step process, where the steps shown in figure 5.1 can take place multiple times, leading to further planning and actions until a solution is provided (Coughlan and Coghlan, 2002).

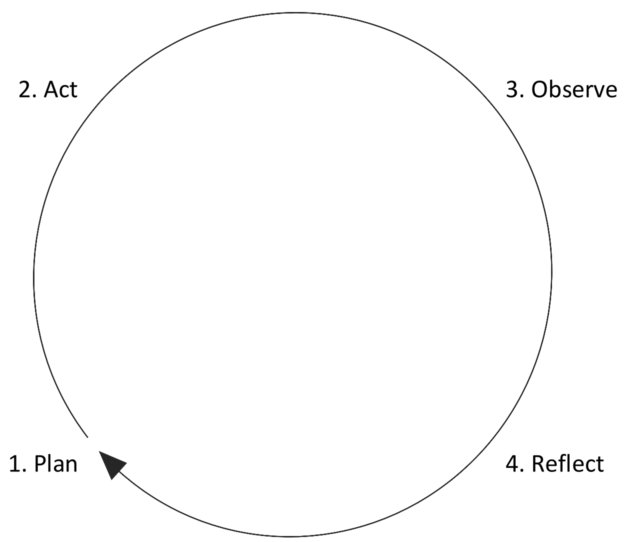


Figure 5.1.: Cycle of planning, acting, observing and reflecting. *Adapted from Zuber-Skenitt (1993).*

Participatory Action Research (PAR) is a branch of AR and a research approach that aims to understand and change the world in a collaborative fashion, by enabling community participation and problem reflection (Baum, 2006; Reason and Bradbury, 2008). The main characteristic of PAR is its collective and participatory nature, where researchers and participants collaboratively endeavour to understand a problem by collecting and analysing data, which leads to an action that attempts to solve the issue, followed by a reflection on the collected data and action (Baum, 2006). As in AR, PAR is multi-stepped and each action is followed by a reflection that tries to identify and evaluate the outcomes of the action.

Rasmussen (2004) argues that during an AR approach, the researcher, due to the democratic and active involvement with the community, plays many different roles such as '*facilitator*', '*process-planner*', '*analyst*', '*evaluator*', '*co-ordinator*' and/or '*change agent*'. Indeed, in ExCiteS, when we collaborated with forest communities and local intermediaries, we had a multifaceted role, where we also acted as '*logistics planners*', '*interface designers*', ' *software engineers*', and '*ICT consultants*', as the following chapters show.

Due to its democratic nature, its multi-step process and the community's active involvement, an AR approach was adopted to allow a deeper insight into the communities' problems and enable a collaborative design. The rest of this section demonstrates, through examples in literature, how AR has been already applied in the areas of ICT4D and HCI to facilitate collaborations and problem solving.

Action Research within ICT4D

Software development and ICT solutions usually originate from the West and are designed to cover the needs of users in urban settings (Siew et al., 2013). However, designing and developing ICT systems for rural communities in remote and extreme environments introduces a range of social, practical, technological challenges (Irani et al., 2010; Vitos et al., 2013). As pointed by Blake (2015), the issue for ICT4D practitioners is how to design a solution for a problem where they don't understand the local context. Similarly, a local community cannot appreciate the importance and potential of an ICT-based solution, since they lack the technical knowledge. As a result, previous studies have estimated that half of attempted projects, conducted under similar circumstances, have been total or partial failures (Heeks, 2002, 2010). In addition, Oyugi et al. (2008), demonstrate that methodologies applied in western contexts for evaluating ICT systems do not apply in different contexts.

Thus, designing, introducing, evaluating and adapting ICT with communities with little or no prior exposure to technology, and whose socio-cultural background and understanding may differ widely from those within which such systems are usually designed, necessitates an iterative, participatory approach with deep understanding of the local complexities (Garcia and Gorenflo, 1998) and the use of appropriate technology as defined by Schumacher (1973). AR, and especially PAR, proved to be appropriate approaches for collaboratively seeking the solution to the issue concerning the community and reflecting valuable lessons from the implementation and deployment of the system (Siew et al., 2013). Blake (2006) argues that AR will not necessarily lead to a solution, but it is a starting point for investigating the situation and reflecting on the impact of the design method.

AR has been used in a variety of projects. Indicatively, Blake et al. (2001), have used a form of AR called *critical action research*, to develop an ICT system for semi-literate animal trackers to capture data on animal behaviour (Blake et al., 2001; Blake, 2002). Yeo et al. (2011) have used the AR approach to deploy a telecentre in a remote community in Malaysia. The authors have employed PAR as a way to acquire knowledge about the community, collaborate with them and at the same time teach the community regarding the ICT skills, improving the project's sustainability.

Action Research within HCI

According to Hayes (2011), the iterative and reflective cyclic approach that AR employs, has many similarities to the HCI methods and UCD (see section 5.2.2). Within HCI, participatory and UCD approaches are highly encouraged as users have detailed knowledge of the organisation and the work practices that system designers don't possess (Hayes, 2011). The main advantage of using AR in HCI studies, is the very close relationship between the researcher and the communities, which facilitates useful insights, limits the influence that the researchers might have on the participants due to the collaborative nature of AR and finally enables the direct application of theory to practice (Kjeldskov and Graham, 2003).

Although HCI and AR have grown in terms of importance in the past 20 years, there are very few examples of AR applied in HCI and definitely fewer than expected (Kock, 2015). Kjeldskov and Paay (2012), conducted a literature review of 144 HCI studies and report that only one was applying AR to further understand the context of the project. According to the authors, this reflects the bias towards artificial setting research and the lack of an established body of knowledge around AR and HCI (Kjeldskov and Paay, 2012). This might also happen because AR can be time-consuming, since the researcher is actively collaborating with the participants, and it has a series of ethical considerations that the researcher should take into account beforehand, which could add an additional financial and implementation overhead (Kjeldskov and Graham, 2003).

Still, due to the democratic nature and due to the positive results on ICT and ICT4D initiatives, I hypothesize that AR can provide a reliable framework in combination with a UCD approach (section 5.2.2) and usability engineering methodologies (section 5.2.3) to facilitate a collaboration amongst communities and technology practitioners in order to resolve particular issues, lead to better ecological validity and reflect on applied solutions.

5.2.2 User-Centred Design

Although the necessity for including human capabilities in the design of technological systems has been recognised since 1969, when Nickerson stated that '*the need of the future is not so much for computer oriented people as for people oriented computers*' (Nickerson, 1969, p. 178; as cited in Ritter et al., 2014, p. 33), the development of early computer systems was primarily technology-driven (Oviatt, 2006). Historically, ICT practitioners believed that users were able to adapt to every system they were presented with through instruction, training and practice (Oviatt, 2006). This design attitude lead to system designs that did not meet the users' expectations and caused anger and frustration (Abras et al., 2004). As Norman suggested through his best-seller book *The Psychology Of Everyday Things*, which was later renamed to *Design of Everyday Things*, problems and poor performance are not caused due to humans' lack of ability or understanding, but due to bad design and by not taking into consideration the users' needs (Norman, 1988, 2013).

User-Centred Design (UCD) attempts to tackle the bad designs, by allowing end-users to influence the design outcome (Abras et al., 2004). UCD, also referred as Human-Centred Design (HCD), is both a philosophy for designing a product and a set of methods for achieving the development of a usable end-product (Abras et al., 2004). In UCD, the central idea is that the best designed products or services derive from understanding the needs of the people who will use them. This approach focuses on user needs, wants and goals, while the designer's role is to capture and transform these needs into useful interfaces (Preece et al., 2002; W3C, 2004; Medhi, 2007; Saffer, 2009; IBM Design, 2013).

The term User-Centred Design originates from Norman's research work at the University of California San Diego (UCSD), in the 1980s, and became popular after the publication of his book *User Centered System Design: New Perspectives on Human-computer Interaction* (Norman and Draper, 1986). Nowadays, UCD has become an established, and highly used approach for designing ICT systems and UIs (Abras et al., 2004; Mao et al., 2005; Norman, 2005), where users are involved in every stage of the development, ideally from the beginning of a project, to provide insights that drive the design decisions being made. In addition, users are consulted to evaluate the suggested solutions according to the degree they satisfy their needs and goals (Saffer, 2009).

The importance of UCD is reflected by the fact that it has been standardised by the International Organization for Standardization (ISO) in 1999 (formerly ISO 13407) and subsequently in 2010 (ISO, 2010). According to the ISO 9241-210:2010 (ISO, 2010), UCD is defined as:

> *Human-centred design is an approach to interactive systems development that aims to make systems usable and useful by focusing on the users, their needs and requirements, and by applying human factors/ergonomics, and usability knowledge and techniques. This approach enhances effectiveness and efficiency, improves human well-being, user satisfaction, accessibility and sustainability; and counteracts possible adverse effects of use on human health, safety and performance.*

The standard describes 6 primary principles for designing a product (ISO, 2010):

1. The design is based upon an explicit understanding of users, tasks and environments.
2. Users are involved throughout design and development.
3. The design is driven and refined by user-centred evaluation.
4. The process is iterative.
5. The design addresses the whole user experience.
6. The design team includes multidisciplinary skills and perspectives.

As described in ISO 13407 (ISO, 1999), the core component of UCD is an iterative process consisting of four primary design activities and is illustrated in figure 5.2. The first step is to recognise the need for a human centred design, and then the process starts by identifying the context of the development product, recognising the users and the tasks that they perform with the system. Next, the usability goals and requirements of the product are set up by identifying design guidelines and constraints. In the next step, new prototypes and products are developed based on HCI guidelines and the established requirements. After that, there is an evaluation of the designed products against the requirements captured earlier. This step might lead to the rise of new requirements or to the refinement of the existing ones. Finally, the process is iteratively applied until the designed system meet the goals and requirements of the users (ISO, 1999; Jokela et al., 2003; ISO, 2010).

UCD shares many similarities with AR, especially the cyclic, iterative process that it follows. As described in previous sections, AR also follows a spiral process with the major phases being '*planning, acting, observing and reflecting*' (Zuber-Skenitt, 1993). In addition, as AR practitioners adapt their research methodology depending on the project context, similarly UCD practitioners adapt their techniques and methodologies depending on the users' needs and context (Hayes, 2011). Figure 5.3 captures the overlaps between AR, UCD, HCI and usability engineering (section 5.2.3). However, according to Hayes (2011), there is a major difference between the two concepts. Although the purpose of AR is to solve a problem, the ultimate goal is the contribution to scholar knowledge. On the other hand, UCD's end

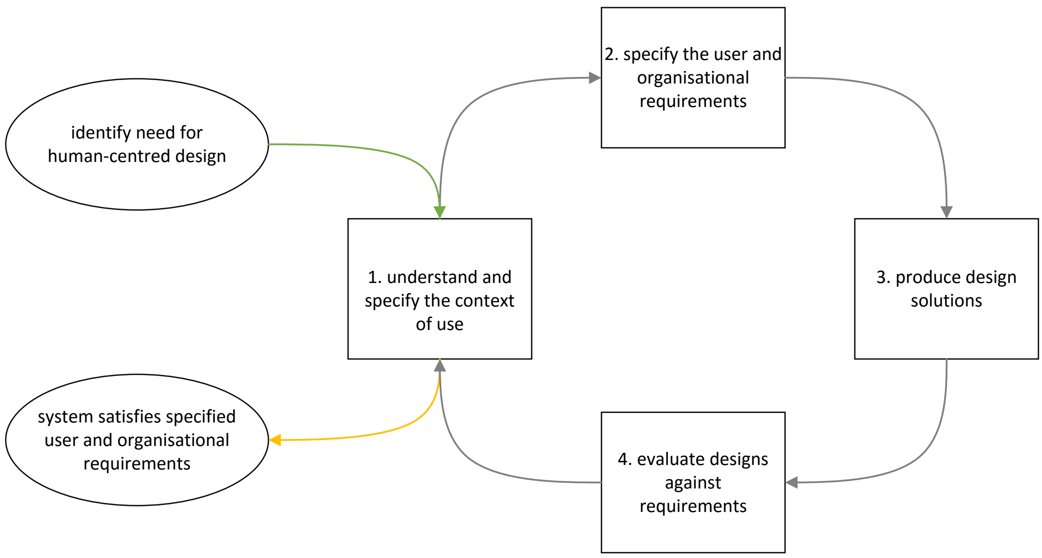


Figure 5.2.: Activities of UCD. *Adapted from ISO 13407:1999 (ISO, 1999) and (Jokela et al., 2003).*

product is an artefact, whether that is a technological system or a tangible product (Hayes, 2011). In addition, as Hayes (2011) points out, studies on HCI follow a more strict and rigid approach than traditional social science and for instance focus on statistical significant surveys and conducting research with research subjects rather than research participants etc. This approach does not always fit with the community engagement and participatory problem solving.

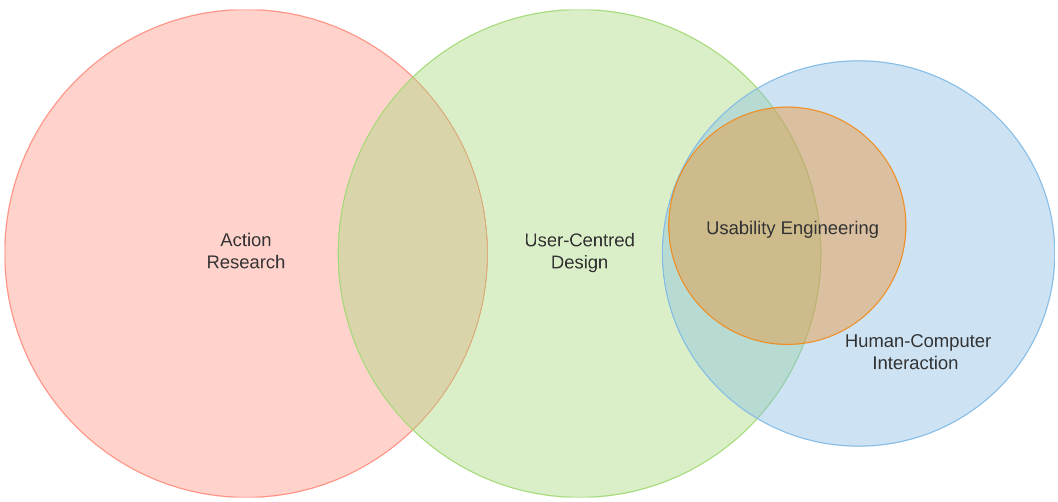


Figure 5.3.: Overlaps between of AR, UCD, HCI and Usability engineering.

UCD within ICT4D

As seen in section 4.1.1, UCD has a rich tradition in ICT4D projects and employed to assist researchers to capture and understand users' needs and transform them into relevant user interfaces (Roman and Colle, 2002; Colle, 2005; Medhi, 2007; Gruijters and Blake, 2008; Lalji and Good, 2008; Devezas et al., 2014). Therefore, it is common in ICT4D projects for researchers to initially try to identify the problem by conducting interviews with the stakeholders (i.e. community members, NGOs etc.), before designing and introducing their solutions. A prototype is then designed implementing the basic functionalities of the new system and trying to tackle the challenges identified in the first stage. The prototypes are then introduced to users for evaluation. Finally, after the phase of evaluation, the feedback collected by the users along with the observations are used to redefine the requirements and improve the prototype. Following the iterative approach described in the previous section, this process is usually followed more than once until the final system is usable or the evaluation results met the predefined goals for the research team.

Although UCD is commonly used in ICT4D, when designing for users who are so different and so remote from the designer, there are also known difficulties in applying methods from UCD. The literacy level and computer skills of users provide challenges for effectively communicating their requirements, goals and the functionalities of an ICT system (Teka et al., 2016). In addition, researchers argue that users in ICT4D projects usually lack the experience to comment or suggest alterations, or to contribute in participatory exercises (Winschiers, 2006; Chetty and Chetty, 2007; Chetty and Grinter, 2007; Winschiers-Theophilus, 2009; Rodil et al., 2012). Maunder et al. (2007) argue that participatory design methods, as the ones used in UCD, are not applicable and might be problematic until the users acquire the necessary IT familiarisation. According to the authors, UCD fails to understand the broader and complex environment of these users and as a result early-stage prototyping techniques, such as paper-prototyping are problematic (Maunder et al., 2007). Other research indicate that participants with low IT skills have trouble interacting with prototypes as they found difficulties in connecting abstract sketches to software (Marsden et al., 2008), and they often misinterpret or misunderstand design prototypes (Medhi et al., 2006; Molapo and Marsden, 2013).

Winschiers-Theophilus (2009) argues that not only the design of ICTs should be aligned with the local socio-economic context and challenges, but also the methods for designing and evaluating these systems should be adapted accordingly (Winschiers, 2006; Winschiers-Theophilus, 2009). Hence, this research provides an ideal opportunity to reflect on the process and make an additional contribution by trying to answer research question RQ 2 of this thesis.

Conclusion

As seen in the literature, UCD has been used in numerous occasion in ICT4D. Hence, I argue that a combination of AR that was already employed by ExCiteS, in combination with UCD methodologies is the most appropriate for this individual research. By using UCD design process on the efforts to develop an ICT solution for communities to capture their local, environmental knowledge, we rely on a standardized framework, which has been validated by several years of application, and at the same time allows for flexibility with regards to methods used in the UCD activities. Next, by combing it with AR, and adopting methods from both approaches, this research can achieve a deeper understanding of the complex psychological and social context (see section 3.1) and reflect on the solutions to provide valuable knowledge to the research community and meaningful solutions for the communities.

5.2.3 Usability Engineering

Usability refers to the experience a user is receiving when interacting with a product, system, software of mobile application. In terms of usability, a system should be useful and achieve its desired goal, usable and without making errors and finally to be attractive for people to want to use it (Dix et al., 2003). Another important definition of usability can be extracted from ISO 9241-11:1998 (ISO, 1998, definition 3.1), where it is defined as '*The extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use.*' Finally, Nielsen states that '*usability has multiple components and is traditionally associated with five usability attributes: learnability, efficiency, memorability, errors and satisfaction*' (Nielsen, 1993, p. 26).

As described in section 5.2.2, UCD is an iterative process, where users are involved in every design and development step. Usability engineering, is an important part of UCD, for evaluating whether the proposed solutions meet the users' needs and goals. As figure 5.4 shows, the importance of usability is to enable users to achieve their goals and meet their needs in a specific context of use (Bevan, 1995; ISO, 1998; Jokela et al., 2003). The *goals* reflect the objectives of the user and what he is actually trying to accomplish by using the system. The *context of use* includes the users, tasks, equipment and the environment. The *tasks* describe the activities that the users perform in order to achieve the goals. The equipment includes the necessary materials to perform the tasks such as hardware and software. Finally, the *environment* refers to the physical, social and cultural environment such as workplace and organisational structure (Bevan, 1995).

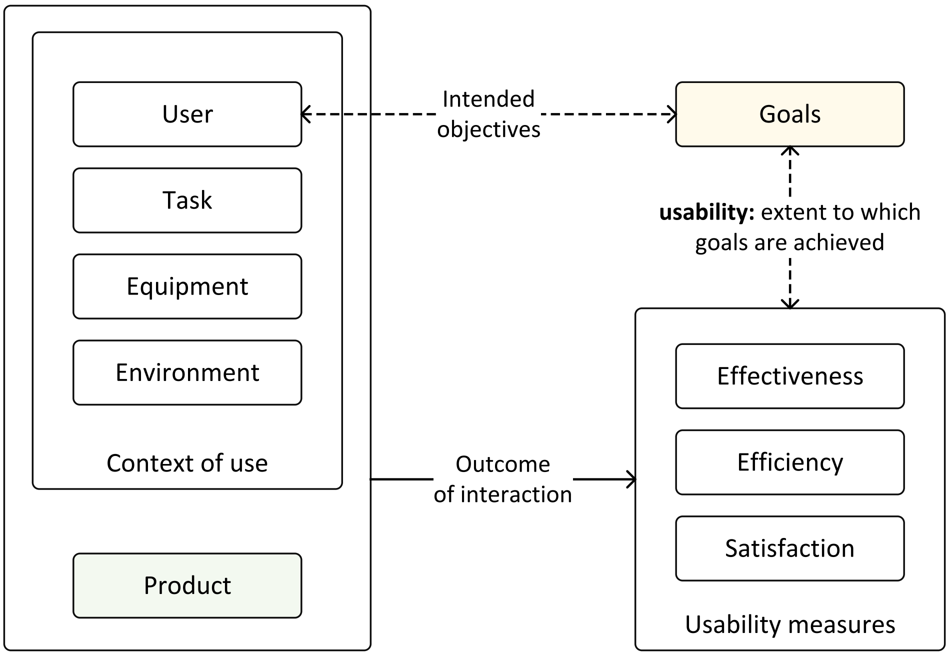


Figure 5.4.: Usability framework. *Adapted from ISO 9241-11:1998 (ISO, 1998).*

The following section explores the different *usability measures* to decide the extent to which a product can be usable, followed by a description of the *evaluation methods*, used to discover and ensure the usability of products against user requirements and needs.

Usability Measures

Traditionally, usability focuses on how well users can learn to use a product and achieve their desired goals by using it. Although there is no consensus among researchers and practitioners on how to ensure usability, there are many proposals on how to evaluate it. The *usability measures* can be used to determine '*the extent to which a product is usable in a particular context*' (ISO, 1998), and thus discover the usability of different products when used in the same context. According to Welie et al. (1999), there are three popular sets of usability measures that mostly differ on details and terminology (table 5.1).

As shown in table 5.1, the measures proposed by the ISO 9241-11 standard are efficiency, effectiveness and satisfaction. *Efficiency* is defined as '*the resources expended in relation to the accuracy and completeness with which users achieve goals*', e.g. how much time users spent on a task and in how many steps they accomplish the given goal (ISO, 1998; Welie et al., 1999; Jokela et al., 2003). The most common

Table 5.1.: Usability measures. *Adapted from Welie et al. (1999)*

ISO 9241-11	Shneiderman	Nielsen
Efficiency	Speed of performance	Efficiency
	Time to learn	Learnability
Effectiveness	Retention over time	Memorability
	Rate of errors by users	Errors/Safety
Satisfaction	Subjective satisfaction	Satisfaction

metric for efficiency is time needed for a participant to complete a task. *Effectiveness* is defined as '*the accuracy and completeness with which users achieve specified goals*' (ISO, 1998; Welie et al., 1999; Jokela et al., 2003). Usual metrics for effectiveness include the completion rate (the percentage of correct tasks in relation to the total tasks) and the number of errors that a participant makes in order to complete a task. Finally, *satisfaction* is referring to the '*freedom from discomfort, and positive attitude to the use of the product*', and is typically measured with post-task questionnaires (ISO, 1998; Welie et al., 1999; Jokela et al., 2003).

The ISO usability measures (ISO, 1998) provide an abstract and theoretical approach on evaluating a product which might not be practical and applicable in many scenarios (Welie et al., 1999). Shneiderman and Nielsen provide two alternative sets of measures that are essentially identical apart from the used terminology (Nielsen, 1993; Shneiderman, 1997). Nielsen (1993) extends the ISO measures by adding *Learnability* which measures whether the system is easy for a user to learn, and subdividing effectiveness into *Memorability*, which measures whether the system is easy to remembered over a long time of not using it, and *Errors/Safety* that refers to the errors users make while using the system and how easy it is for them to recover from those errors.

Dix et al. (2003) follow a different approach and define a list of concrete elements that influence usability, rather than providing an abstract framework as shown in table 5.2 (Welie et al., 1999). According to Welie et al. (1999), this set of measures gives the designer concrete rules to improve a product. However, this categorisation does not include efficiency and error rate, which are considered indicators of usability by other authors.

Table 5.2.: Usability measures according to Dix. *Adapted from Dix et al. (2003).*

Learnability	Flexibility	Robustness
Predictability	Dialog initiative	Observability
Synthesizability	Multi-Threading	Recoverability
Familiarity	Task Migratability	Responsiveness
Generalizability	Substitutivity	Task conformance
Consistency	Customizability	

Evaluation Methods

Usability evaluation is essential to ensure that a system meets the users' requirements and enables them to achieve their goals and can be done during the design of a system or afterwards (Welie et al., 1999). According to Holzinger (2005) there are plenty evaluation methods that can be organised into two principal categories, the *inspection methods* that can be conducted without end users and *test methods* that are performed with end users. Inspection methods are valuable for rapid and cost effective evaluations, throughout the development process and they can identify minor and major problems. However, as Holzinger (2005) points out, they lack the interaction with end users and thus are unable to identify the needs of unknown users. Test methods on the other hand, are more time consuming, harder to organise and more expensive, however they provide unique insights on how users are interacting with the designed product or interface and help identify issues.

Inspection methods This is a set of methods for evaluating and improving the usability of a product, or interface, by testing it against established standards. Primarily, inspection methods are conducted by experts and are very practical when there are time or economic constraints (Dix et al., 2003). The most common inspection methods are *heuristic evaluation*, *cognitive walkthroughs* and *action analysis* (Holzinger, 2005).

Heuristic evaluation is the most common, rapid and low cost method, where experts judge the usability of a product based on well-established guidelines and principles (Holzinger, 2005). Heuristic evaluations usually require more than 3 evaluators, and Nielsen and Molich (1990) demonstrated that 3-5 experts result in identifying 40-60% of the usability issues in a system. In order to ensure unbiased results, each evaluator inspects the product atomically. Afterwards the results are aggregated and the evaluators can discuss the results to finalise their report (Dix et al., 2003).

Cognitive walkthrough is a task-focused method where experts evaluate the usability of a system by performing detailed step-by-step tasks from the perceptive of the end user (Holzinger, 2005). Experts imagine being the users and try to answer questions on each step regarding the learnability of the system by analysing the mental process required to execute the step. The advantage of cognitive walkthrough is the low cost and rapid evaluation that can provide the design team with valuable insight from the user's perspective. The disadvantage is the unintentional bias of the evaluators towards the tasks, and their distance from the end users (Wharton et al., 1994).

Action Analysis (also known as Keystroke-Level Analysis), divides the task that a user performs into smaller, individual actions (such as keystrokes and mouse movements) and calculates the time required to finish each of the actions. In this manner, the evaluator predicts how long it will take an expert user to perform a task. As a method, it is quick and easy to apply but it only evaluates the system's performance rather than other usability measures such as learnability and memorability (Holzinger, 2005).

Test methods Conducting usability evaluations with end users is of uttermost importance, as it provides direct and valuable information on the people who actually use the development system and it reveals issues that users face (Holzinger, 2005). From the existing methods for testing usability with users, the most common are *thinking aloud*, *field observation* and *questionnaires*.

Thinking aloud is based on the principle of an end user trialling the evaluated system and being asked to constantly think out loud (Holzinger, 2005). Users are encouraged to say whatever they feel such as what they are looking at, what they are doing and how they are feeling. Having users expressing their thoughts leads to insights on performance, preference, errors and user's expectations and misconceptions (Dix et al., 2003; Holzinger, 2005). As a method it is cheap and flexible, as it does not require any special equipment and can be used at any stage of a product design (Nielsen, 1993). According to Nielsen (1993, p. 195) '*thinking aloud may be the single most valuable usability engineering method*'. However, thinking aloud has its drawbacks as it feels unnatural to the majority of users. As a result, users instead of providing raw thoughts will filter them and provide an alternate version after the fact (Nielsen, 1993; Dix et al., 2003; Nielsen, 2012). Finally, prompts and clarifications from the researcher might influence the responses of the users and their behaviour (Nielsen, 2012). An improved version of thinking aloud, named *constructive interaction*, attempts to solve some of the mentioned issues. By including two users who mutually explore the system and discussing their progress, this method creates a more natural environment than working with single users (Als et al., 2005; Holzinger, 2005).

In field observation, the researcher visits the users in their natural environment (workplace, house etc.) while they are using the system. During the field observation, the researcher stays almost invisible and takes notes in an unobtrusive manner (Dix et al., 2003; Holzinger, 2005). Video recording assists to make the process less obtrusive, but leads to material that is hard and time consuming to analyse. As Holzinger (2005) states, videos require 10 times more time to be analysed. Another complementary method to field observation, is automatic data logging, where the system is recording each interaction with the system. Logging is cheap, usually easy to implement and unobtrusive and ideal for long-term studies (Dix et al., 2003). However, logging lacks '*semantics*' and provides no information on why a user performed certain actions (Dix et al., 2003).

Finally, query methods (such as questionnaires and interviews) are an alternative method to capture user's needs, goals, preference, experience, satisfaction and perspective regarding the system, reaching a wider group (Dix et al., 2003; Holzinger, 2005). The philosophy behind these methods argues that the best approach to find if the user's requirements are met is by '*asking the user*' (Dix et al., 2003). However, as Holzinger (2005) points out, user's opinions and preferences do not always comply with their actions during a task, and do not always reveal the real usability issues of a product. Questionnaires are fast to create and administer and lead to great amounts of data, but for a survey to be significant, at least 30 participants are required (Holzinger, 2005). Another form of querying the user are interviews, where depending on the style of the interview, the user is encouraged to elaborate on his views regarding the system and explain the issues that he is facing while using it (Holzinger, 2005). Although more time consuming, interviews are more flexible than questionnaires as depending on the evaluators' experience the interview can be adapted depending on the context and the user (Dix et al., 2003).

5.2.4 Methodologies in this thesis

UCD

As noted, UCD has been used in numerous occasions in ICT4D, hence it was selected in this thesis to better understand the context of use, evaluate decision trees and improve the participants interaction with them. The first step in the UCD approach is to understand the context of use. As described in chapter 3, the context of this thesis is the Congo basin and the numerous indigenous and settled communities that live in the area.

The cornerstone of the UCD approach, after specifying the context of use, is identifying the user requirements and goals (Jokela et al., 2003; ISO, 2010). Gathering detailed functional requirements and acquiring a good contextual understanding provide a firm foundation for the success of any ICT project (Ross and Schoman, 1977; Wiegers and Beatty, 2013). Thus, the initial step in any software development life cycle model is the gathering of requirements through in-depth discussions and interviews with all stakeholders who will use the system (Robertson and Robertson, 2012). Typically, a software engineer or a designer will interact directly with the stakeholders of the project in order to understand the context and their needs.

However, given the restrictions of direct access to end communities (as explained in section 3.2), traditional UCD methods for eliciting requirements such as *focus groups*, *interviews* and *questionnaires* were not applicable. In addition, ICT4D and HCI4D literature suggests that users due to their lack of IT experience, they cannot communicate their goals and requirements in relation to an ICT system. To mitigate these, an alternative approach was trialled were the initial list of requirements was drafted after a series of interviews with an anthropologist, who had a close collaboration with the local communities and acted as a proxy, and by analysing the literature and similar ICT4D initiatives (see chapter 6).

However, this initial list of requirements has a numbers of limitations and bears the risk of being biased since only one representative of the communities (the anthropologist) was employed to extract the requirements and might not be representative for the communities as a whole. To mitigate that risk, as the research progressed, more anthropologists, with local knowledge, were interviewed and later two field trips were arranged for the author to amend the list of requirements by observing the participants and conducting interviews with them (see chapters 7 and 8).

While in the field, the methodology to engage with communities and introduce the project scope and the various collaborators followed the Free, Prior and Informed Consent (FPIC) approach as described in Stevens et al. (2014). When consent was granted, methods such as 'card sorting' were used in order to create categories and structure the decision trees.

Following the design of decision trees, participants were introduced to the technology and taught how to use the mobile devices and software. Afterwards, usability testing was applied to evaluate whether decision trees were applicable given the local context. In the next section, the usability engineering methods used are described.

Usability Engineering

As seen in the Usability Engineering section, the usability of an ICT system allows users to achieve their desired goals in a easy, attractive and error-free manner. Therefore, the lack of usability of 'decision trees' can influence participant's performance and the validity of the collected data, which will cause failure to the participatory mapping project. In addition, as presented in chapter 4, although decision trees are used in the ICT4D literature, one of the limitations of previous work was the lack of usability evaluations to assert the effectiveness of systems and evaluate whether the approach could be replicated in other scenarios.

Thus, one of the goals of this research was to measure the usability of the decision trees. Given the limited time and resources of this thesis, in combination with the constraints in accessing participants that was described in chapter 3, it was decided to that the most important usability metrics to research for were *Effectiveness* and *Satisfaction* (or *Learnability*, *Memorability*, *Errors* and *Satisfaction* on the Nielsen scale) (see section 5.2.3). Time and efficiency, although they are important factors in other contexts, do not seem to be so important in these cases. For instance, in a participatory mapping of local resources, it is very significant for a participant to accurately complete the procedure of mapping a single point of interest (e.g. a banana tree) without any errors, while the time is of less importance. For instance, it does not matter if the participant maps a specific tree in 2 seconds rather than 5. Also, collaborating with non-literate participants and excluding text prompts or help files, makes *Memorability* a very important factor for users to be able and confident to use the system after a long time of absence. Finally, *Satisfaction* is vital for engaging users and therefore has a massive impact on the successful deployment of ICT systems.

Regarding this research, a different set of *inspection* and *test* methods were used during the different UCD iterations of this research, that will be discussed in detail in the coming chapters. Heuristic evaluations (see section 5.2.3) were considered unsuitable for these case studies from the first moment, since most interface guidelines target specific platforms and their goal is to provide a common look and feel for every application in the system and resolve common interaction issues that users face. For instance, Microsoft (2015) offers recommendation to developers on how to create user interfaces for the Windows operating system. Similarly, Apple Inc. (2015) and Android (2015b) provide guidelines for designing smartphone applications for the iOS and the Android OS respectively that have a common look and feel with the rest of the Operating system (OS). Heuristic guidelines target these common usability and interaction issues that users already familiar with technology face, and do not apply universally when designing systems for non-literate participants.

Similarly, cognitive walkthroughs are challenging when the end users are so different from the usability experts conducting the walkthroughs and were initially rejected. However, due to lack of participants, an alternative version of cognitive walkthrough was devised, where field experts (i.e. anthropologists with vast experience of the communities) participated in the walkthrough and acted as proxies to end users to identify major usability hurdles.

In terms of test methods, during two field trips, this research applied a 'think aloud' method to elicit feedback from the participants. More specifically, it used a version of think aloud named 'constructive interaction', were two users mutually explore the system and describe their actions in the process. Finally, think aloud was used in conjunction with field observations and participants' interviews to evaluate the usability of different prototypes.

5.3 Case studies

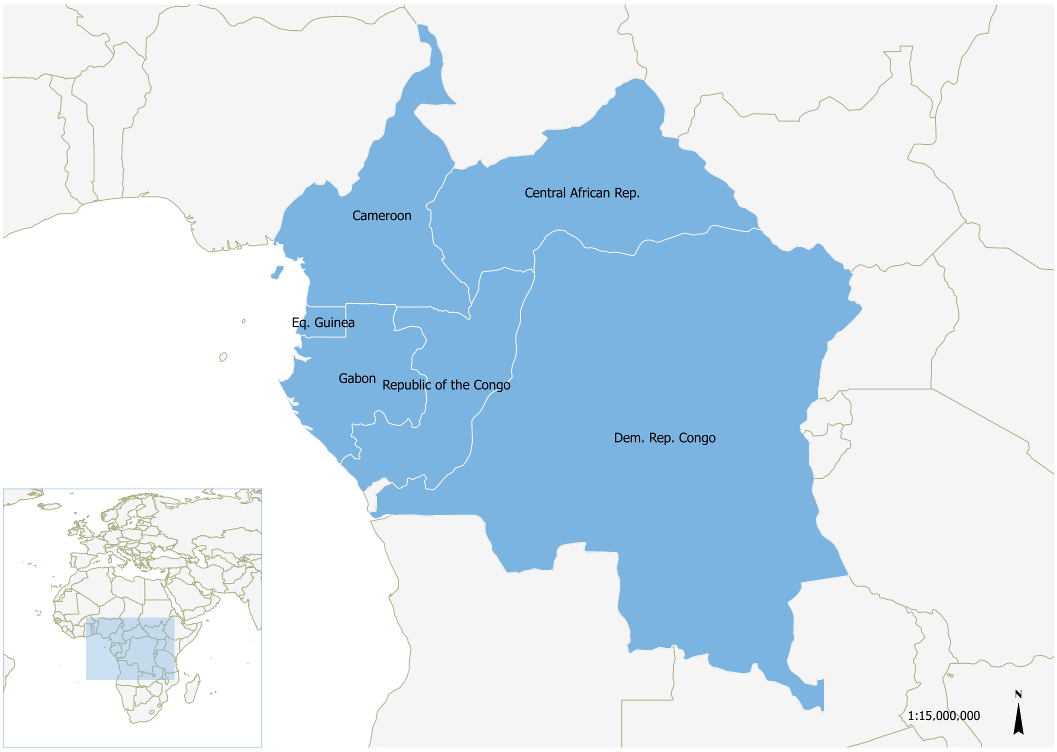


Figure 5.5.: Case studies map.

This thesis consists of three case studies, all taking place in the RoC (figure 5.5) and focusing on enabling local communities to participate in socio-environmental monitoring schemes. Hence, these case studies provided the opportunity to conduct research on the appropriateness of decision trees as UIs to capture geographical data in order to support these schemes. The three studies are themselves independent case studies and were conducted in collaboration with different communities and stakeholders. As a result, each case study had different requirements but they are highly connected since the core challenges and goals were similar. Thus they are briefly presented here to provide the context of this research, then each of them is independently and in depth presented in following, separate chapters.

Following an UCD approach, this research composed of three iterations, and each case study provided the basis for further research depending on the results of the previous (figure 5.6). As, however, we will present in the subsequent chapters, in each of the case studies there were multiple sub-iterations while in the field, in order to improve both the prototypes and the approach.

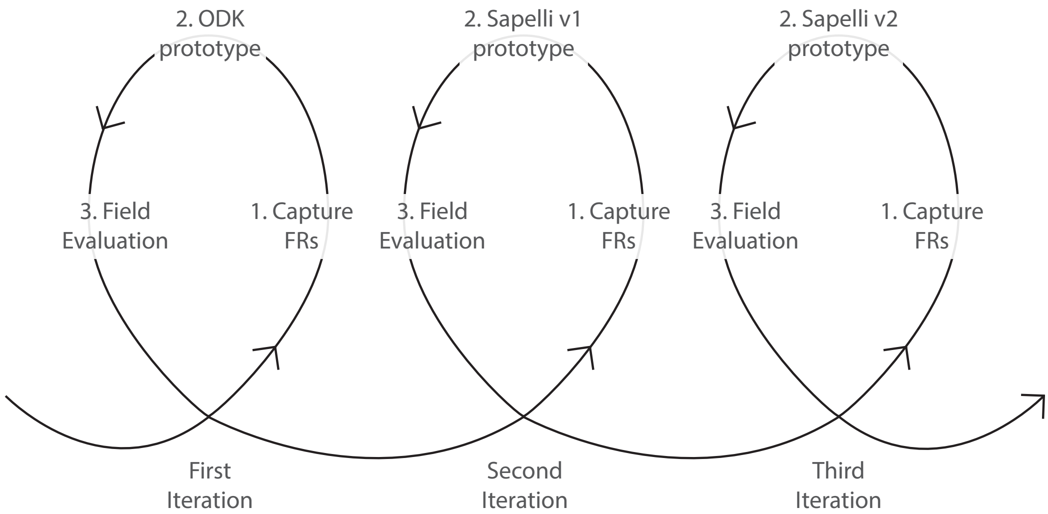


Figure 5.6.: Research iterations.

As explained in chapter 3, collaborating with forest communities, who are generally non-literate and lack prior exposure to ICT, introduces a range of socio-cultural, practical, methodological and interaction challenges which can only be met through participatory and culturally-informed methods of community engagement, interaction design and evaluation. Hence, it is important to be working 'in the wild' as much as possible (see section 4.2.4 for a definition). However, working in these remote and extreme places presents a number of logistical, organisational, legal, financial and security-related challenges which can only be met with the cooperation of locally-situated intermediaries and which often severely limit the time we can actually spend with communities. To alleviate these challenges, we have adopted a creative and flexible approach for the design and evaluation of the ICT tools '*in the wild*', including three major lengthy field visits in 3 years, where we had multiple sub-iterations with different communities, and *on-the-spot* creation and evaluation of new software features and interaction prototypes. As illustrated in table 5.3, this research was composed of three phases, over the course of 3.5 years. Each phase is a separate case study and includes the collaboration with different stakeholders and communities where we applied different methodologies, and new research questions arose as knowledge was acquired after each one of the research phases.

Table 5.3.: Research phases and methodologies applied.

Research phase	Objectives	Methodologies used
Phase 1 Research, Conceptualisation & Feasibility evaluation *(chapter 6)*	• Requirements analysis & literature review to identify the problem, define the boundaries and review existing solutions. • Carry a feasibility study to explore whether an ICT solution is applicable. • Conceptualisation of initial ICT-based solution for enabling the capturing of TEK through decision tree UIs.	• Gathering requirements by collaborating with local experts & from literature. • Development of ICT prototype that supports decision tree UIs. • 'Walkthrough' evaluation of decision trees with experts. • Evaluate decision tree prototypes via proxy.
Phase 2 Deployment & Feasibility evaluation of ICT platform. *(chapter 7)*	• Deployment of new ICT platform that supports data collection via decision tree UIs. • Field evaluation of platform. • Requirements gathering in the field. • Usability & appropriateness evaluation of decision trees.	• Gathering requirements via field deployment. • Ethnographic approach and participant observation. • Participant interviews. • Usability trials of decision trees presented as mini stories.
Phase 3 Usability evaluation & Exploration of alternative user interactions *(chapter 8)*	• Usability evaluation of the ICT platform. • Exploration & evaluation of alternative user interactions for capturing TEK (audio and physical interfaces).	• Requirements gathering via field evaluation. • Ethnographic approach and participant observation. • Participant interviews. • Usability trials presented as real-life scenarios. • 'Think aloud' methods.

In the rest of this section, we present the three iterations in chronological order and we further explain figure 5.6 (sections 5.3.1 to 5.3.3). However, it is worth mentioning that the three case studies follow the same process of (a) capturing Functional Requirements (FRs); (b) designing, implementing and developing a functional prototype; (c) evaluating the prototype in field with local communities (figure 5.6). Next, section 5.3.4 explains the personal contribution of the author in relation to this interdisciplinary project that was conducted within ExCiteS. Finally, section 5.3.5 discuss the ethical considerations when conducting research with non-literate forest communities.

5.3.1 Case study 1: Participatory monitoring of poaching

As seen in chapter 3, the blooming resource extraction industry, in the Congo basin, comes with an extensive infrastructure such as the intrusion of roads that make previously remote areas easier to access by commercial hunters and poachers (Eisen et al., 2014). Hence, poachers have been expanding rapidly in recent years, in part driven by the highly lucrative international trade in ivory and other trophies.

The direct competition with commercial hunters for natural resources, in combination with the exclusion or the access restriction on certain areas of the forest due to conservation efforts, leads to cases of malnutrition and increases mortality rates amongst forest communities (Ohenjo et al., 2006; West et al., 2006). This was problematic for indigenous communities, not only due to over-hunting, but also due to reprisals made against locals by government-run '*eco-guards*', supposedly responsible for controlling poachers but often looking for easier targets (Lewis, 2012b; Caramel, 2017; Corry, 2017; Osborne, 2017; Survival International, 2017).

In 2010 the president and the secretary of the Mbendjele association, inspired by the outcomes of previous collaborations between the community and researchers to map information regarding the logging impact on their lifestyle, asked WCS and ExCiteS to assist them in developing a similar scheme to deal with the issue of commercial poaching, another pressing issue for the community.

In 2012, the newly-formed ExCiteS group took up the challenge and this was a great opportunity for this individual research to investigate the applicability of decision trees to collect data regarding poaching (research question RQ 1). Therefore, the first research goal was to investigate the feasibility of an ICT '*Anti-Poaching*' prototype and draft an initial set of requirements, as this would be the first step of the followed UCD approach. Since this was an collaboration amongst a community and an NGO with limited resources and budget, the proposed ICT tool had to operate on off-the-shelf and affordable equipment and open source software to match their expectations. Since there was already a number of data collection platforms that were employed in ICT4D scenarios and were popular by practitioners and therefore in wide use (see chapter 6), adapting such platforms to support decision trees would make them widely available to this context for TEK gathering. It would be appropriate to evaluate the ability to utilise these platforms and, therefore, the second goal of this case study was to explore if decision trees could be integrated in existing technologies and platforms to make them accessible by non-literate communities (research question RQ 2).

As presented in figure 5.6, this iteration started with capturing the FRs of the project. As noted in section 5.2.4, due to restrictions in accessing participants and the literature suggesting that extracting requirements from non-familiarised with technology participants is challenging, the initial list of FRs was drafted after a series of interviews with a proxy and from the literature. Next, a series of hardware and software decisions had to be made in order to select appropriate technologies for the given context, followed by the development of the first '*Anti-Poaching*' application by modifying the ODK platform (Hartung et al., 2010) to meet these requirements. The resulting app enabled participants to record evidence of poaching activity (geo-located via GPS and optionally augmented with photos and/or audio recordings) using a pictorial decision tree (Vitos et al., 2012; Stevens et al., 2013b; Vitos et al., 2013). The prototype was later evaluated in field by the community in April of 2012. For that reason, an anthropologist was employed to evaluate the prototype in field following a pre-drafted evaluation protocol.

The main purpose of this case study was to draft an initial list of requirements for a data collection platform that would use decision trees to enable participants to collect data. As will be presented in chapter 6, this case study acted as a proof of concept and it produces a list of requirements for later case studies. It provided an initial evaluation of decision trees and it demonstrated that the selected hardware and software worked as expected, but also led to helpful suggestions for future implementations.

5.3.2 Case study 2: Participatory monitoring of logging

In 2013, the ExCiteS group collaborated with the international NGO Forests Monitor and *Cercle d'Appui à la Gestion Durable des Forêts* [Circle of Support for Sustainable Forest Management] (CAGDF), a forestry sector watchdog in Republic of the Congo, to prototype tools for local communities to monitor the socio-economic impacts of logging activities.

Until then, local communities had seen little benefit from the blooming resource extraction industry that was active in their localities. They have had little say in how the logging concessions were managed, and had no recourse if loggers destroyed resources on which they depended. Thus, with the use of ICT tools and similarly to the earlier logging-related projects, locals would be able to give direct feedback on the behaviour of logging companies, and allow them to accurately map important resources they wanted to claim and protect from destruction.

As noted, the initial list of requirements, which was drafted in the previous case study (see chapter 6), has a numbers of limitations and bears the risk of being biased since only one representative of the communities (the anthropologist) was employed to extract the requirements and might not be representative for the communities as a whole. To mitigate that risk, in the second case study, another anthropologist was employed to extend and redefine the FRs (figure 5.6). Following the evaluation of the previous '*anti-poaching*' case study and taking into account the limitations of the ODK-based prototype, in combination with the requirements identified for this particular case study, a new, bespoke software platform for data collection, named **Sapelli**, was developed.

The Sapelli app offered pictorial interfaces with decision trees and it was intended to enable participants to map their resources and feedback on the behaviour of logging activities to CAGDF, who could then assist communities to seek redress for violations of the social aspects of Forest Law, Enforcement, Governance and Trade (FLEGT)[1] and other relevant laws (Stevens et al., 2014) (see chapter 7).

Later a field evaluation was arranged to investigate the technical feasibility of the newly developed Sapelli platform in one hand (answering research question RQ 2), and to test the appropriateness of the *pictorial decision trees* in relation to usability, effectiveness and user experience on the other (attempting to answer research question RQ 1). As will be explained in chapter 7, by the end of this case study, a series of interaction challenges have been identified, as well as cultural differences in terms of evaluating software and conducting structured evaluations '*in the wild*' (see section 4.2.4).

5.3.3 Case study 3: Participatory monitoring of logging

In early 2015, the ExCiteS group collaborated with the forestry company CIB to develop a Sapelli-based application that would allow community members to document and map key forest resources as valuable to them, which could then be verified and removed from the cutting schedule of the timber company. By using Sapelli, CIB hoped to retain their FSC certification on the one hand, and enable the logging company's social team to improve their local understanding of the mapping process by

[1]The FLEGT Action Plan is a European Union (EU) endeavour to address illegal logging and the socio-economic consequences it has on the environment and local communities in the affected areas (European Union, 2015) (see section 7.1).

re-introducing the ability for Mbendjele community members to be directly involved on the other.

In terms of research, this case study acted as the ideal context for conducting detailed usability evaluations to assess pictorial decision trees and alternative user interactions for participants to collect local environmental data (chapter 8). Building on the previous iteration, where usability issues were identified, in this case study two new features in the ICT platform were designed and implemented as potential solutions (seeking to answer research question RQ 1). The first one was *Audio feedback*, a feature offering audio guidance to participants while navigating the pictorial decision tree. The second feature was *Animated transitions* between different nodes of the decision tree to help participants perceive the underlying structure and create visual and mental links between the different screens.

In addition, the previous case study unveiled difficulties in applying Usability Engineering and UCD methodologies for conducting usability evaluations. For this third field trip, strategies for conducting more successful usability evaluations while in the field were drafted (seeking to answer research question RQ 2).

However, our limited time in the field required for an adaptation to the research approach and act based on the results of working with pictorial decision trees and audio feedback. Hence, the planned evaluations with animated screen transitions were skipped and instead physical, tangible interfaces were explored as a novel means to interact with the system, potentially resulting in increased participant performance and satisfaction (see chapter 8).

5.3.4 Project and Research contributions

As noted, this research conducted within the research group ExCiteS and it was a collaborative effort that could not be achieved independently. This section tries to resolve any ambiguity of personal contribution by listing the author's contributions per case study.

Case study 1: Participatory monitoring of poaching

In this case study, my personal contribution can be summarised to the following tasks:

1. **Requirements analysis:** Due to logistical and practical reasons (i.e. cost, lack of invitation letter from local NGOs), it was decided that the initial requirements and potential challenges for the first case study would be obtained from a literature review and by interviewing an anthropologist with local expertise. This list of requirements was used throughout all case studies and was modified or extended depending on the results of each case study.

2. **Evaluation of hardware:** Given the technical constraints, due to lack of infrastructure in LICs, an evaluation of hardware solutions had to be performed.

3. **Evaluation of ICT4D platforms:** As noted, there is a number of platforms already used in ICT4D projects. Since adapting such platforms would significantly contribute in the context of TEK gathering by non-literates, a list of platforms was evaluated. Amongst those, ODK was selected as the most appropriate system.

4. **Development of prototype:** A first '*Anti-Poaching*' prototype was developed to explore the applicability of decision trees on the ODK platform. The prototype took 3 months to develop and modified ODK to a great extend to include UIs with pictorial interfaces only.

5. **'Walkthrough' evaluation:** Cognitive walkthroughs are challenging when the end users are so different from the usability experts conducting the walkthroughs. For that reason, I employed an anthropologist with local experience of the communities to act as an intermediary and perform the cognitive walkthrough. This allowed to identify major usability hurdles before the field evaluation.

6. **Evaluation protocol draft:** An anthropologist was employed to evaluate the prototype in field. As a result, I drafted an evaluation protocol for the anthropologist to follow while in field.

7. **Evaluation analysis and requirements refinement:** Following the evaluation, performed by the anthropologist, I analysed the results and incorporated his observations into the list of requirements.

Case study 2: Participatory monitoring of logging

As noted, this case study was conducted in an interdisciplinary research group and the development of the new platform was a joint research and technological effort.

However, within the group, my personal contribution to this case study can be summarised to the following tasks:

1. **Requirements analysis:** The list of functional requirements that was captured in the first case study was modified and extended during this case study. For this, I interviewed **two** anthropologists operating in the area, **two** local NGOs that acted as a collaborator to the project and finally I participated in a field trip to capture requirements first-hand.

2. **Sapelli platform:** Within the Sapelli platform, I designed and developed the **Sapelli Launcher** (an Android replacement that provides a text-free app launching interface), led the **design of the UI** that employed decision trees, led the **data transmission** and developed the **Sapelli Relay** and the **Sapelli Server**, all components necessary either to answer the research questions of the thesis or for ICT4D projects, operating in LICs where internet infrastructure is intermittent or missing.

3. **Walkthrough evaluations:** Similarly to case study 1, when the Sapelli prototype was implemented, I conducted walkthrough evaluations with **two** anthropologists to identify major usability issues.

4. **Provided training:** The main principle behind Sapelli was the option to easily modify a project and change the structure of a decision tree or the icons. Since data collection projects might change due to participant's understanding or requirements, the anthropologists or local NGOs representatives had to be able to modify the Sapelli projects. Thus, I provided training sessions to the anthropologists of the research group on how to '*code*' and manage Sapelli projects.

5. **Deployment of system:** While in field, I collaborated with the two local NGOs to deploy the Sapelli platform and provided training to NGOs members on how to receive and review incoming data from the field.

6. **Participants observation:** While in field, I conducted an ethnographic approach of observing the participants while they were introduced to the Sapelli platform by anthropologists and NGOs representatives. These observations led me to identify a list of usability issues.

7. **In situ UI improvements:** While in field, and while identifying a list of usability issues, I did in situ UI improvements that were received well by participants.

8. **Usability evaluation:** I drafted a usability evaluation protocol to be used while in field and conducted usability evaluations with 30 participants.

9. **Participants interviews:** Part of the usability evaluation protocol involved unstructured interviews with the 30 participants to elicit feedback on the software and any problems that they encountered.

Case study 3: Participatory monitoring of logging

As in case study 2, this case study was conducted in an interdisciplinary research group with joint research and technological efforts. However, within the group, my personal contribution to this case study can be summarised to the following tasks:

1. **Requirements analysis:** Once again, the list of requirements was extended during this case study. For this, I interviewed again **two** anthropologists operating in the area, representatives from CIB and finally participated in a field trip to capture requirements first-hand.

2. **Sapelli platform:** Within the Sapelli platform, I designed and developed the two features that were introduced to resolve the usability issues, improve the recognition of icons. The first was an *audio feedback* mechanism and the second was a system with *physical* interfaces.

3. **Walkthrough evaluations:** Similarly to case studies 1 and 2, when the new Sapelli features were implemented, I conducted walkthrough evaluations with **two** anthropologists to identify major usability issues.

4. **Deployment of system:** While in field, I collaborated with members of the cartographic team of CIB to deploy the Sapelli platform and provided them with training on how to receive and review incoming data from the field.

5. **Design of decision tree:** While in field, my goal was to evaluate the new Sapelli features. For that reason, I collaborated with the social team of CIB to design a decision tree to be used on the evaluations. Given the recommendations extracted on the previous case study (depth of tree less than 5 and less than 60 icons), I designed a tree of 2 levels (depth) and 26 icons.

6. **Record audio descriptions:** While in field, I recorded one the research assistants speaking aloud descriptions for each of the 26 icons and for each of the

screens in the local Mbendjele language. These audio descriptions were used in the audio feedback feature during the evaluations.

7. **Evaluation protocol draft:** Given that the previous case study unveiled that structured usability evaluations and hypothetical task scenarios do not work well with non-literate participants, I drafted an evaluation protocol that involved active participation and performing practical tasks such as mapping an actual tree.

8. **Usability evaluation:** While in field, I visited 4 different communities (visiting some of them twice) and conducted usability evaluations on the audio feedback and whether it compliments pictorial decision trees with 48 participants.

9. **Evaluate physical interfaces:** While in field, given the results of my evaluations with audio feedback, I shifted the rest of the field trip to the evaluation of physical interfaces with 32 participants.

10. **Participants interviews:** Following completion of the tasks, I conducted interviews with the participants, comprising both structured and semi-structured questions. The interviews were video-recorded for later reference and transcription. During the interviews, I tried to facilitate a discussion on usability of and user satisfaction with the app, and to identify the reasons for some participants' poor performance on certain tasks.

5.3.5 Ethical considerations

Ethical consideration and reflective practice are central to the general methodology of the ExCiteS group, and were therefore applied throughout this research. Throughout my research I followed the University College London (UCL) Ethics Committee Guidelines[2], the ESRC Research Ethics Framework, as well as the International Society of Ethnobiology Code of Ethics[3] and the Association of Social Anthropologists Code of Ethics[4] – both of which provide a stronger stance in their requirement for respect and reciprocity in the relationship with indigenous groups, intermediaries and researchers who are involved in the research. Given the broad work, in different contexts and collaborating with different communities, it was not feasible to draft a generic ethics approval for the whole project, but different ethical approvals for particular evaluations and evaluations were granted as the research progressed.

[2]UCL Ethics Project ID Number: 4598/002
[3]http://www.ethnobiology.net/what-we-do/core-programs/ise-ethics-program/code-of-ethics
[4]http://www.theasa.org/ethics.shtml

In this section, the ethical considerations and strategies followed in regard to working with humans and managing their personal data are discussed.

Working with humans As this research focuses on the development of a system that is designed for people with no experience of digital technology, and frequently with low or no literacy, a FPIC methodology to introduce and evaluate the software always used (Lewis and Nkuintchua, 2012; Stevens et al., 2014). As explained in Stevens et al. (2014), the protocol was applied from the first contact with a community of potential participants, and the community's consent was asked and granted multiple times. Throughout the process the research team and any other stakeholders were thoroughly introduced. We explained, in broad terms, The purpose of the project and the potential role for the community were explained, in broad terms; and what the researchers understood to be the associated risks and benefits were then explained. At every stage discussion was encouraged and questions were asked to gauge the extent to which key issues have been understood and debated.

Personal data As noted, data collection initiatives are work in progress that shift due to new requirements from the communities or the stakeholders. As such, it was expected that different data protection strategies will be evaluated and ethical approval will be requested for each of the projects separately. However, since all case studies are still in pilot stages, none of those was employed. During the experimentation and evaluation phase of all case studies, limited personal data has been collected from interested community members such as gender and age, and therefore it is not possible to identify individuals.

The vision for this research is to provide flexible tools for communities to capture their TEK, and following an AR approach, the data collected are decided after consultation of the local stakeholders and the communities. Hence, some of the activities that communities can design may include the collection of sensitive data, such as evidence of harmful logging or poaching activity. In conducting research with participants in these projects, we have been exposed to this sensitive data. In order to avoid any potentially harmful consequences, all ethnographic and interview data that has been collected, in any form, has been anonymised, encrypted and stored on secure media.

5.4 Summary

This chapter has introduced the methodology through which this research has been carried out. It firstly explored how AR and UCD were applied to facilitate better collaboration between researchers, practitioners and communities that enabled a deeper understanding of the social context of this research (sections 5.2.1, 5.2.2 and 5.2.4). Then it explored the importance of Usability Engineering, and the different usability methods that were used to evaluate how well forest participants could learn to use the ICT system and achieve their desired goals (sections 5.2.3 and 5.2.4).

Then this chapter illustrated the three case studies this research has focused on, the first dealing with participatory monitoring of poaching (section 5.3.1) and the subsequent two concerning the participatory monitoring of harmful logging (sections 5.3.2 and 5.3.3). Finally, a clear contribution of the author per case study has been provided in section 5.3.4 to resolve any ambiguity.

6 Case study 1: Participatory monitoring of poaching

> *We see addressing rural poverty and creating opportunities for sustainable livelihoods as a critical element in turning the tide on wildlife poaching and trafficking.*
>
> — **Helen Clark**
> (Administrator of the UNDP)

This chapter[1] introduces the initial technological approach and work completed in 2012, to provide forest communities in the Republic of the Congo with a tool to monitor and report poaching activities in their local forest. Specifically, this chapter introduces the case of the Mbendjele, a forest hunter-gatherer tribe living in northern Congo-Brazzaville, who wish to monitor and map the activities of commercial poachers in their area (section 6.1). In terms of this research, this case study endeavours to define the context and works towards answering the two research questions, as defined in chapter 4.

In section 6.2, the list of functional requirements for the ICT platform are presented along with the methodology employed to draft the list, while section 6.3 briefly describes the hardware and software evaluation conducted to explore different elements to cover the requirements. Next, section 6.4 presents the work undertaken to meet the identified requirements, and develop the prototype that would employ interfaces with decision trees to allow participants to capture geographical data regarding poaching.

[1] Parts of this chapter are published in:

a) Vitos, Michalis, Matthias Stevens, Jerome Lewis and Muki Haklay (2012). "Community mapping by non-literate citizen scientists in the rainforest". In: *Bulletin of the Society of Cartographers* 46.1-2, pp. 3–11.

b) Vitos, Michalis, Matthias Stevens, Jerome Lewis and Muki Haklay (2013). "Making Local Knowledge Matter: Supporting Non-literate People to Monitor Poaching in Congo". In: *Proceedings of the 3rd ACM Symposium on Computing for Development*. ACM DEV '13. Bangalore, India: ACM, 1:1–1:10. ISBN: 978-1-4503-1856-3. DOI: 10.1145/2442882.2442884.

c) Stevens, Matthias, Michalis Vitos, Jerome Lewis and Muki Haklay (2013b). "Participatory monitoring of poaching in the Congo basin". In: *Proceedings of the GIS Research UK (GISRUK)*. URL: http://www.geos.ed.ac.uk/~gisteac/proceedingsonline/GISRUK2013/gisruk2013%5C_submission%5C_12.pdf.

Following a user-centred design approach (see section 5.2.2 for definition), the prototype was later evaluated in the field by the Mbendjele and it was evaluated (section 6.5). After the evaluation, the feedback collected by the participants along with the observations and log analysis were used to redefine the requirements, and led to further development and experimentation in two following case studies, described in later chapters (see chapters 7 and 8).

6.1 Helping communities to fight poaching

As already introduced in chapter 3, the rainforest of the Congo Basin hosts more than 29 million rural people, including up to 500,000 indigenous people (Lewis and Nelson, 2006), while research suggests that there are more than 900,000 Pygmies in the forests of Central Africa (Olivero et al., 2016). Amongst them, the Mbendjele are the indigenous people of northern Republic of the Congo (see figure 3.1 on page 29). As expert hunters and gatherers of wild produce (such as bush meat, fish, reptiles, caterpillars, honey and fruits) they move through huge areas of forest over the course of the year visiting different resource centres and following social opportunities as they arise (for a map of the area, check figure 3.1 on page 29 and figure 5.5 on page 83). According to Lewis (2002, p. 73), Mbendjele members have been reported to have moved up to 800 km in a year. Even to this day, it is normal for every able-bodied, male member of the tribe to complete such a long trip at least once in their lifetime (Lewis, 2002, p. 73). The Mbendjele, as the rest of the forest communities, are inseparably dependant on the rainforest for their livelihood which is affected by natural resource management efforts and the blooming resources extraction industry. The latter comes with an extensive infrastructure such as the intrusion of roads that make previously remote areas easier to access by commercial hunters and poachers (Lewis, 2002; Yasuoka, 2006; Eisen et al., 2014).

The Mbendjele are deeply concerned about over-hunting by commercial poachers in their traditional hunting grounds (Lewis, 2012b). The direct competition with commercial hunters for wild resources, in combination with the exclusion, or the access restriction, on certain areas of the forest due to the conservation efforts, leads to cases of malnutrition and increases mortality rates amongst forest communities (Ohenjo et al., 2006; West et al., 2006). In addition, professional poachers cause the introduction of even harsher conservation measures in order to protect the endangered species dwelling in the forest. This vicious circle keeps disenfranchising local forest and Bantu[2] communities, and excludes them from their traditional lifestyle (Lewis and Nelson, 2006; Survival International, 2017).

[2] In the Congo Basin there is an enormous range of Bantu and Ubangian farmer and fisher communities, living in open spaces, adjacent to the rainforest, most commonly referred to as Bantu (Conquest, 2014).

Poachers operate from small camps dispersed in the forest and are typically armed with shotguns, Kalashnikovs and rifles, posing a threat to locals, especially those who try to meddle in their activities (Lewis, 2012a). In addition, the hundreds of vicious wire snare traps the poachers leave concentrated in small areas ravage animals indiscriminately and pose a danger to hunter-gatherers and their children as they move in the forest (Lewis, 2012a).

In response to the increasing issue, the government or local conservationists organise paramilitary patrols tasks, called 'Eco-guards', responsible for controlling commercial hunters. Although there is evidence that the patrols are effective in certain situations, for instance when organising road blocks that search out-coming from the forest vehicles, they pose a serious issue for many forest peoples (Lewis, 2012b; Caramel, 2017; Corry, 2017; Osborne, 2017; Survival International, 2017). Commercial poachers tend to enjoy relative impunity as they bribe eco-guards, or other law enforcers, and are often part of larger networks supported by local elites keen on profiting from this highly lucrative business (Survival International, 2017). Eco-guards looking for easier targets often visit Mbendjele and other local communities where they too often resort to violence and abuse (Survival International, 2017). The Mbendjele experience this as unacceptable persecution for something that they see as their birth right, to live by hunting and gathering wild foods from the forest as their ancestors have done since time immemorial (Lewis, 2012b).

Poaching is also a major concern and preoccupation of civil society, local conservationists from WCS and CIB, the largest logging company in the Republic of Congo and one of Central Africa's major forestry processing companies. Until now, local organisations have not found an effective way to capitalize on the Mbendjele's extensive knowledge of poachers' whereabouts and habits to control them more effectively (Lewis, 2012b).

Based on the community resource mapping that was carried out with support from the local logging company CIB (presented in section 4.1.2), in 2010 two prominent Mbendjele approached WCS and ExCiteS to design a new tool that would allow them to record this knowledge, similar to the earlier tool used to map their resources to protect them from damage from logging activities (Lewis, 2012a). The WCS manager was responsible for organising the eco-guard patrols, and he discussed with the Mbendjele the idea of enabling the community to collect poaching data. Together they discussed which issues they would like to monitor and, from the eco-guards point of view, which observations (e.g. sightings of poacher's camps, traps, dead animals, etc.) would need to be recorded to effectively arrest the poachers. During the meeting, the ExCiteS representative sketched up icons representing different issues and observations until participants felt satisfied that all aspects were covered.

At the end of the meeting, there was a list of icons that represented the various poaching information that participants could capture.

Given this context, it is important to note that when working in ICT4D projects, establishing relationships with intermediaries who have a sustained local presence, sufficient expertise in local conditions, and who are trusted by local communities is vital (Sein and Furuholt, 2009, 2012; Aal et al., 2014; Stevens et al., 2014; Therias et al., 2015). Such partnerships work to lend legitimacy to a project from the point of view of participants and other local stakeholders. Without local partnerships it is extremely difficult to get access to such communities. Therefore, in terms of this individual research, the collaboration between the Mbendjele, WCS and ExCiteS, was an important opportunity that gave access to a case study to evaluate whether decision trees could be employed to allow participants to collect poaching data and therefore work towards answering research question RQ 1, but also explore the challenges in such an endeavour (research question RQ 2).

In the rest of the chapter, the individual work of this research is described, to identify the requirements for the ICT system that would use decision trees to capture poaching data (section 6.2), the evaluation of different hardware and software components (section 6.3), the development (section 6.4) and finally the evaluation of the prototype (section 6.5).

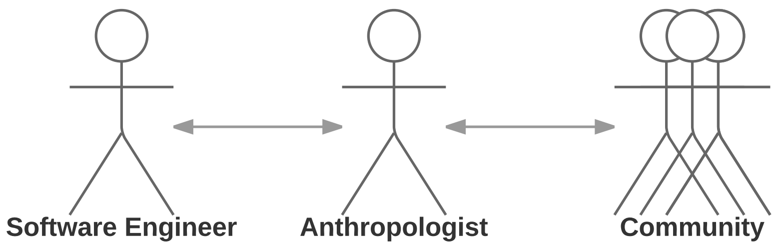
6.2 Requirements Analysis

UCD was selected, as mentioned in section 5.2.4, to better understand the context of use, evaluate decision trees and improve the participants interaction with them. As noted in section 5.2.2, the cornerstone of the UCD approach, after specifying the context of use, is identifying the user requirements and goals (Jokela et al., 2003; ISO, 2010). Gathering detailed functional requirements and acquiring a good contextual understanding provide a firm foundation for the success of any ICT project (Ross and Schoman, 1977; Wiegers and Beatty, 2013). Thus, the initial step in any software development life cycle model is the gathering of requirements through in-depth discussions and interviews with all stakeholders who will use the system (Robertson and Robertson, 2012). Typically, a software engineer or a designer will interact directly with the stakeholders of the project in order to understand the context and their needs (figure 6.1a).

However, given the restrictions of direct access to end communities (as explained in section 3.2), traditional UCD methods for eliciting requirements such as *focus groups*, *interviews* and *questionnaires* were not applicable. In addition, ICT4D and

HCI4D literature suggests that users, due to their lack of IT experience, cannot communicate their goals and requirements in relation to ICT systems (see section 5.2.2). Maunder et al. (2007) argue that participatory design methods and early-stage prototyping techniques, such as paper-prototyping are problematic, while other research indicates that participants might have trouble interacting with prototypes as they found difficulties in connecting abstract sketches to software (Marsden et al., 2008). As a result, paper prototypes and other early-stage prototyping techniques were rejected. Instead, it was decided that a full functioning prototype would be developed and evaluated, after the requirements elicitation phase. To mitigate with all these issues, an alternative approach was trialled were the initial list of requirements was drafted after a series of interviews with an anthropologist, who had a close collaboration with the local communities and acted as a proxy (figure 6.1b), and by analysing the literature and similar ICT4D initiatives [such as Liebenberg et al. (1999), Liebenberg (2011), Lewis (2012b) and Liebenberg et al. (2017)].

(a) Typical requirements gathering



(b) Requirements gathering in this case study

Figure 6.1.: Typical requirements gathering compared to the one applied in this case study.

As presented in section 3.2, the most important challenges and difficulties identified after the interviews with the anthropologist and the literature were social, technological and security related (see table 3.2). In order to try and understand the challenges in designing a system that incorporates pictorial decision trees (research question RQ 2), the list of captured requirements was grouped into *General*, *Usability*, *Security* and *Hardware* requirements for easier reference. The *Usability* requirements refer mostly to research question RQ 1, while the rest endeavour to answer research question RQ 2. The full list of requirements is presented in table B.1 (in appendix B.1).

This initial set of requirements, was refined and amended in later stages and was used as a reference throughout this thesis. Other UCD methods for listing requirements, such as '*personas*' were not employed. Personas, for instance, are fictional characters that summarize an audience target group and allow designers to communicate how users behave (Cooper et al., 2007, p. 62). However, personas are time-consuming and difficult to design, with information being overemphasized or oversimplified (Garcia, 2014), and can also introduce additional risks to ICT4D projects (Peter, 2015). As a result, only the table of requirements was used throughout the thesis to communicate the participants' needs and goals.

However, this initial list of requirements has a numbers of limitations and bears the risk of being biased since only one representative of the communities (the anthropologist) was employed to extract the requirements and might not be representative for the communities as a whole. To mitigate that risk, as the research progressed, more anthropologists, with local knowledge, were interviewed and later two field trips were arranged for the author to amend the list of requirements by observing the participants and conducting interviews with them (see chapters 7 and 8).

6.3 Hardware and software evaluation

As noted, paper-prototypes might be problematic for ICT4D contexts, and instead it was decided that a full, working prototype would be deployed for field evaluation. Hence, the top, initial priority was to find fit-for-purpose devices and charging solutions to be used for the ICT prototype.

UCD suggests a firm understanding of the context and use of appropriate solutions. Additionally, researchers studying the impact of ICT in LICs, report high percentage of failures (Heeks, 2002; Sey and Fellows, 2009; Heeks, 2010) (see section 2.8). One of the reasons for failure, is the introduction of technologies that are not consistent with the local infrastructure. Hence, it was vital to select software and hardware components that fit the local conditions and would allow a successful deployment. The success of the case study would also affect our ability as ExCiteS to conduct research in the area, as it would lead to subsequent case studies and collaborations.

The hardware would dictate the development environment and the available software and, in brief, the devices had to be robust enough to endure the adverse rainforest condition, and the rough treatment that was expected by the participants, be affordable and equipped with decent GPS capabilities to collect geographical data. The selection of the hardware is described in appendix B.2, but since the focus of this chapter is on the development and the evaluation of prototypes with decision trees, hence, it moves on the software evaluation.

In terms of software, as presented in appendix B.3, there was already a number of data collection platforms that were employed in ICT4D scenarios and were popular by practitioners and therefore in wide use. Adapting such platforms, to operate with decision trees, would make the development of any application widely available to this context of TEK gathering and contribute towards a successful project. Hence, at that stage it was also explored whether decision trees could be integrated in existing technologies and solutions to make current platforms accessible by non-literate communities (see appendix B.3).

6.4 Prototype development

Following the selection of the open-source platform, ODK (see appendix B.3), the first prototype Anti-Poaching application was built on top of a modified version of the ODK Collect application for Android, and it was coded on Java. Since ODK was designed to be used by literate participants, it was offering textual forms for data collection, which were adjusted in order for ODK to fit for use in this case study.

As a remainder, in the scope of our case study, a '*decision tree*' is a type of diagram that represents a question which the participant has to reply and is a structure in which the leaves represent classifications or answers to the question, while the in-between nodes represent categories or groups that lead to these classifications. For instance, figure 6.2 shows a minimal decision tree which asks the user to provide his preferable mode of transport. The available choices are *Car*, *Bike*, *Bus* and *Tube*, while *Private* and *Public* modes of transport are classifications that lead to the answer. Users can navigate the decision space by repeatedly selecting a child node until they reach a leaf node, which represents a final selected value.

In terms of structure, ODK is using the XForms standard (W3C, 2003, 2015) to describe a project and supports sequential forms, where users have to answer one by one a series of questions until they reach the end of the project. However, a decision tree is a highly linked structure, where the tree is representing a **single question** and the in-between nodes act as classification groups that lead the user to the answer,

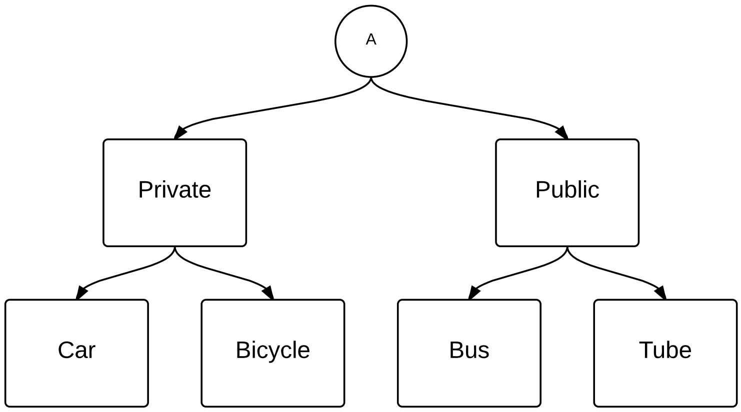


Figure 6.2.: Example of a simple decision tree about transport modes.

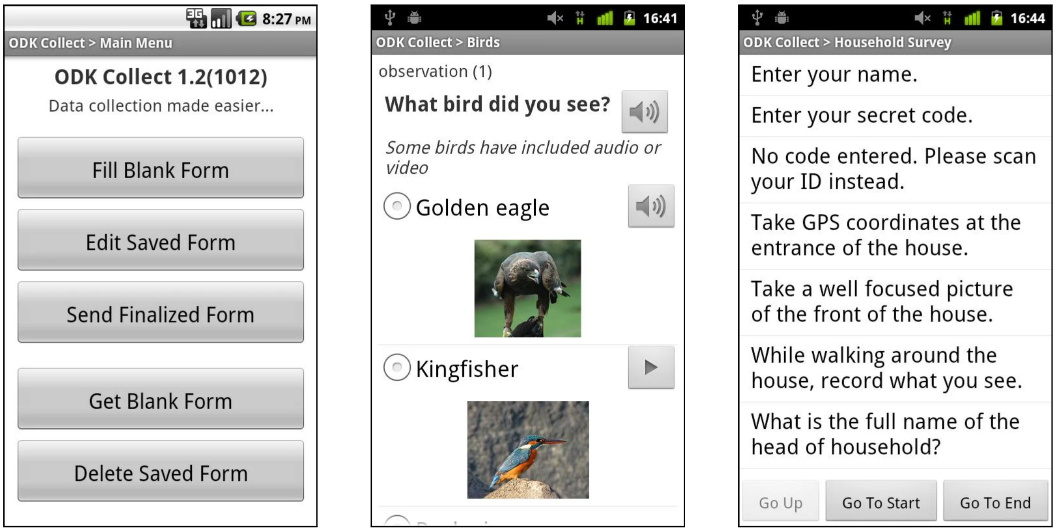
which can be selected via one of the leaf nodes. Decision trees are not natively included in ODK, but it included skip patterns, where depending on the answer, a subset of questions could be skipped. For instance, in a simple survey with 5 questions about consumers' habits, there could be a question asking if the participant does smoke. If he/she does, then the next question could be how many cigarettes per day, and if he/she does not then this question could be skipped. However, the order is still sequential as the 5 questions will be asked one after the other, except for the one with the cigarettes per day that may be skipped. This skipping feature of XForms was utilised, and a series of skips was designed, to achieve a decision tree structure in ODK. The decision tree is presented later in section 6.4.1, yet it is interesting to mention here that the resulting structure worked as intended; however, the Xform code ended up being verbose and cumbersome to modify or maintain. Listing 6.1 shows part of the XForms for a tree with 59 icons spread across 4 levels. The majority of the code is omitted here for simplicity and compactness, but the full Extensible Markup Language (XML) code for the Anti-Poaching prototype is presented in appendix D and consisted of 1,174 lines.

Listing 6.1: Part of Anti-Poaching XForms implementation

```
<!-- Part of the namespace is omitted here for simplicity/compactness -->
<h:html xmlns="http://www.w3.org/2002/xforms" >
  <h:head>
    <h:title>AntiPoaching</h:title>
    <model>
      <itext>
        <translation default="true()" lang="default">
          <text id="/AntiPoaching/pressed_4/4.1:label">
            <value form="image">jr://images/4.1.jpg</value>
            <value>4.1</value>
          </text>
          <!-- Rest of the block is omitted here for simplicity/compactness -->
        </translation>
      </itext>
      <instance>
```

```
        <AntiPoaching id="AntiPoaching">
          <start/>
          <end/>
          <today/>
          <deviceid/>
          <subscriberid/>
          <simid/>
          <phonenumber/>
          <pressed_home/>
          <!-- Rest of the block is omitted here for simplicity/compactness -->
        </AntiPoaching>
      </instance>
      <bind jr:preload="timestamp" jr:preloadParams="start" nodeset="/AntiPoaching/start" type="dateTime"/>
      <bind jr:preload="timestamp" jr:preloadParams="end" nodeset="/AntiPoaching/end" type="dateTime"/>
      <bind jr:preload="date" jr:preloadParams="today" nodeset="/AntiPoaching/today" type="date"/>
      <bind jr:preload="property" jr:preloadParams="deviceid" nodeset="/AntiPoaching/deviceid" type="string"/>
      <bind jr:preload="property" jr:preloadParams="subscriberid" nodeset="/AntiPoaching/subscriberid" type="string"/>
      <bind nodeset="/AntiPoaching/pressed_home" required="true()" type="select1"/>
      <!-- Rest of the block is omitted here for simplicity/compactness -->
    </model>
  </h:head>
  <h:body>
    <select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_home">
      <label>Home Grid</label>
      <item>
        <label ref="jr:itext('/AntiPoaching/pressed_home/1:label')"/>
        <value>1</value>
      </item>
      <!-- Rest of the block is omitted here for simplicity/compactness -->
    </select1>
    <!-- Rest of the block is omitted here for simplicity/compactness -->
    <upload mediatype="audio/*" ref="/AntiPoaching/pressed_1.2.3.1">
      <label>1.2.3.1</label>
    </upload>
    <!-- Rest of the block is omitted here for simplicity/compactness -->
  </h:body>
</h:html>
```

Relating to UIs, ODK Collect heavily relied on textual information for guiding users through the data collection process (figure 6.3). It supported pictorial icons, arranged on a grid, but these icons were still part of a textual form and were not appropriate for use with non-literate participants as they would cause confusion and frustration (figure 6.3b). Hence, the most important modification made on ODK Collect was to remove any textual information. Another equally important alteration that was made, was to let the application run in full screen. Hence, the Android status bar (normally shown at the top of the screen, showing the time, battery level, signal strength, etc.) and the title bar of the application itself were hidden to avoid confusing or distracting the participants. What was left was a minimalistic, entirely graphical interface in which icons were arranged in a grid, as shown in figure 6.4.

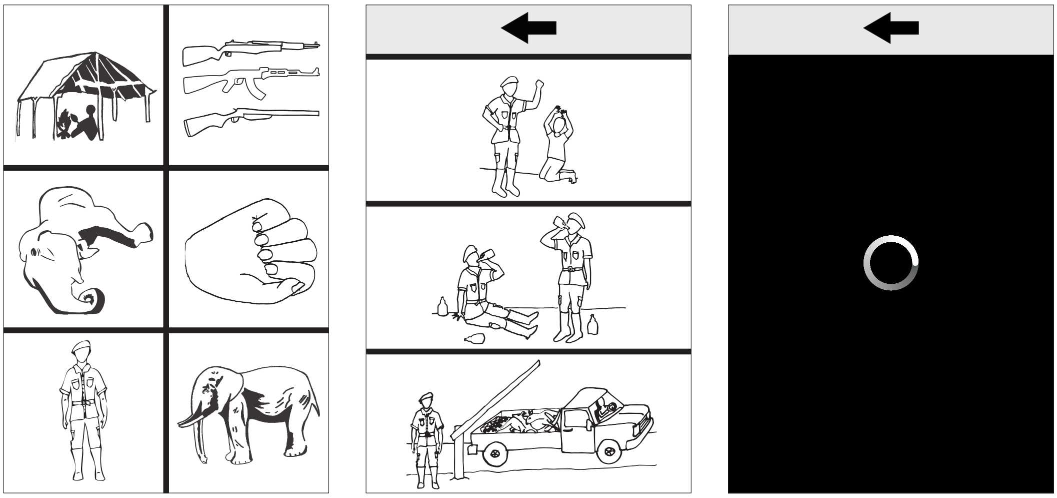


(a) Management of forms **(b)** Form with icon support **(c)** Overview of questions

Figure 6.3.: ODK Collect User Interface. *Source: Open Data Kit (2015b).*

ODK Collect was designed to support multiple projects and thus having different forms that the user can pick from to fill out. For that reason, there was a management UI, where the user can select which project he/she wants to work on as shown in figure 6.3a. However, such a screen would be confusing in an Anti-Poaching prototype, since the participants would have only one project to work with. As a result, ODK was altered to skip the management screen and load the Anti-Poaching project on default.

Finally, in terms of navigation, when reaching the end of a form on ODK, the user was presented with a confirmation screen with the options to finalise the observation by saving the form and exiting. After saving the form, the user returned to the management screen in figure 6.3a. Since the management and confirmation screens, were considered confusing and potentially frustrating for non-literate participants who wouldn't know how to proceed at that stage, ODK was modified to skip the confirmation screen and loop back to the start of the form, ready for the user to make a new observation. To indicate that a complete observation was completed, ODK was extended to play a beep sound when saving an observation and loop back to the start of the form.



(a) Main screen. **(b)** Eco-guard behaviour. **(c)** GPS waiting screen.

Figure 6.4.: User interfaces for Anti-Poaching system

6.4.1 Decision tree

On the finalised prototype, the points to be collected were represented by pictographs, and arranged in a decision tree. The choice of icons and their arrangement in the tree derived from the meeting of Mbendjele representatives with WCS and ExCiteS representatives (section 6.1). Figure 6.5 shows part of that decision tree's structure. The icons represented various signs of poaching activity (e.g. camps, footsteps, hidden weaponry, traps, rotting or abandoned game, smuggling of bush meat or trophies), cases of abusive or corrupt behaviour by eco-guards (e.g. harassment of locals, drinking on the job, taking bribes), and sightings of live animals or other natural resources that indicate good forest health.

In that first version the decision tree consisted of 59 distinct icons spread across 4 levels (figure 6.5). For a larger version of the decision tree, see appendix E. For this research, it was interesting to investigate whether a decision tree offering such a large number of different options would work and be comprehensible, despite the fact that the participants had a say in the drawing of the icons.

6.4.2 Navigation

On the prototype, every observation started with the main menu shown in figure 6.4a, corresponding to the top level of the tree. The user could navigate to a lower level by touching on one of the icons on the touch-screen, and he/she was then presented with a new, more specific set of choices. At every level except the top one a back button allowed participants to go back one level in case they made a mistake, as shown in figure 6.4b. When the user had reached the bottom level of the tree, this

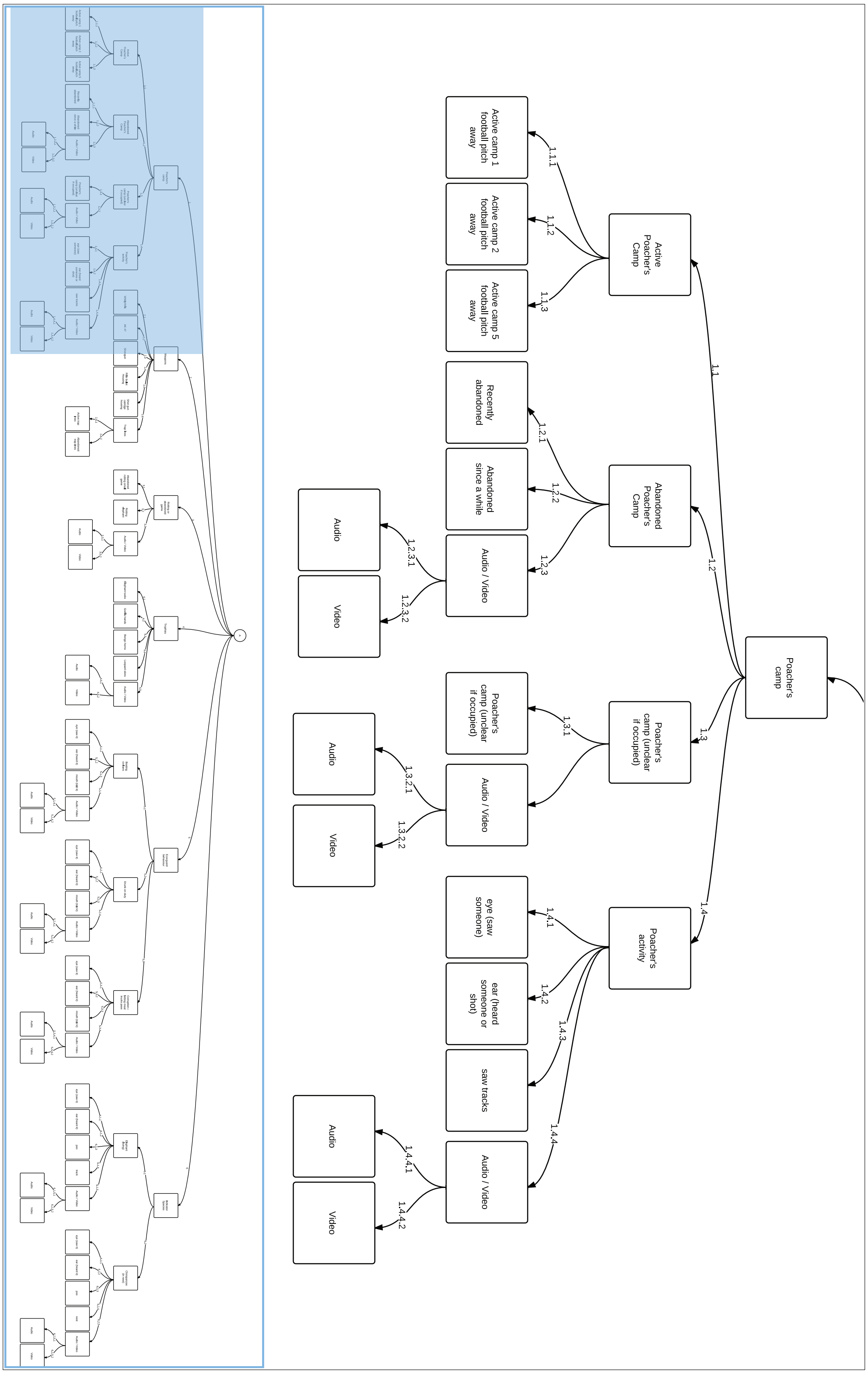


Figure 6.5.: Part of decision tree regarding poachers' camps.

meant that a complete, specific observation (e.g. a recently abandoned poacher's camp) was described. At that point the observation could be complemented with an audio recording, a photo or a video, as a means of providing additional information and evidence. After that the device would try to obtain geographical coordinates from the built-in GPS receiver in order to geo-tag the observation. While waiting for the coordinates, the user was presented with a waiting screen, as an experimental method to indicate to the participants the system status and that the device is unavailable (figure 6.4c). When the coordinates were obtained, the observation, along with multimedia attachments and coordinates, was automatically saved to the memory card of the device, without any further user interaction. To indicate that the data was successfully stored a beep sound was played. Finally, the application was operating in continuous loop, meaning that at the end of each complete observation it went back to the main menu, ready for the user to make a new observation.

Finally, other features such as multimedia screens (see appendix B.4.3), screens that allowed participants to securely login in the device (see appendix B.4.1) and to repost observations from a safe distance (see appendix B.4.2) were designed and implemented. However, it is not in the scope of this chapter to describe those.

6.5 Evaluation

In order to evaluate the feasibility of the approach, the different technological, methodological and software elements of the approach had to be tested and evaluated. The evaluation was done in two stages, initially the prototype was tested in London by conducting a cognitive walkthrough (section 6.5.1), and later was tested in field by the Mbendjele (section 6.5.2).

6.5.1 Cognitive Walkthrough

Before a field trip was organised, and to ensure that the prototype would be efficient and usable, a *cognitive walkthrough* was performed, as it is a low-cost, fast and effective method to gather primary insight on the usability of the prototype (see page 79). However, cognitive walkthroughs are challenging when the end users are so different from the usability experts conducting the evaluation.

Instead, an alternative version of cognitive walkthrough was developed and applied, where field experts (in this case an anthropologist) participated in the walkthrough and acted as a proxy for the end users to identify major usability hurdles. For this reason, the anthropologist was presented with the prototype and with a set of goals to perform (i.e. record the position of a poacher's camp), subdivided in a number of tasks (box 1). For each task, he had to answer a set of usability questions such as '*Will the user know what to do?*', '*Will the user see how to do it?*' and '*Will the user understand the received feedback?*'.

Box 1 Usability Tasks

- **Task 1**

Imagine that you walk in the forest and you spot a poacher's camp.

Subtask 1: You go near the camp and you see that there are poachers around. Use the system to report it.
Subtask 2: You go near the camp and you see that it was emptied a long time ago. Use the system to report it.
Subtask 3: You go near the camp and you are not sure if it is active. Use the system to report it.

- **Task 2**

Suppose that you walk into the forest and you find a stash of weapons, the weapons are shotguns and AK47s. How would you document that without taking any photos or audio recordings?

- **Task 3**

Suppose that you walk into the forest and you find a rotting elephant. How would you document that and take a photo to inform the local authorities?

- **Task 4**

Suppose that you are walking in the forest and you find a bag with elephant tusks stashed. How would you document that and provide photos of the trophies, along with an audio recording where you explain in detail where and what you found?

- **Task 5**

Suppose that an eco-guard is spotted in your village to beat civilians. How would you use the system to report that to WCS?

- **Task 6**

Suppose that your wife told you about an eco-guard who was drunk while on duty. Can you use the system to report that to WCS and provide an audio where you describe the problem?

Based on the evaluation of the cognitive walkthrough, icons were changed and the structure of the decision tree was adapted.

6.5.2 Field evaluation

Then, when satisfied with the outcome of the cognitive walkthrough, the prototype platform was tested by the Mbendjele over the course of April 2012. Due to logistical and practical reasons, with obtaining a travel visa on time being the most important, it was decided that the evaluation would be performed by an anthropologist of ExCiteS who had an already planned trip in the area and would act as a research assistant for this individual research.

The evaluation plan included the usability tasks that were used in the cognitive walkthrough (box 1). The research assistant was tasked to perform the list of tasks with as many participants as possible, given the secrecy of the project, and keep records of performance times and rates, in order to measure the *Effectiveness* of the application and of decision trees. Given the introduction and training of participants, it was agreed that an FPIC approach would be followed (Stevens et al., 2014), as it has been employed in similar contexts with successful results (Lewis and Nelson, 2006; Lewis, 2012b; Lewis and Nkuintchua, 2012). Next, on return, the research assistant was interviewed to access the success of decision trees.

In addition, given the logistical issues of running usability evaluations 'in the wild', the application was also equipped with a *logging* functionality to better understand the user interactions and study the participants' navigation patterns through the application. The logger produced a comma-separated values (CSV) file with all the decision tree's icons that the user pressed and the exact moment by also saving a timestamp value.

The evaluation was twofold, on the one hand the hardware elements of the approach were tested to make sure that the solution was fit to purpose, for instance the mobile devices were evaluated for their appropriateness (i.e. resistance in harsh conditions, battery life, GPS accuracy etc.) and the charging devices were assessed for their efficiency. On the other hand, the software was evaluated to check whether decision trees can act as a proof of concept for a data collection platform that would enable communities to capture relevant local knowledge. The next section presents the results of this evaluation.

6.5.3 Results

In terms of hardware, this case study delivered promising results and hope for the feasibility of the project. The choice of cheap but yet rugged Android smartphones proved appropriate for the local, harsh conditions, while the battery life was adequate during the training sessions and the built-in GPS receiver delivered quick and reliable readings even under the tropical canopy, resulting in average accuracy of 29.01 metres. These results seemed to meet the hardware requirements of the project. Regarding charging the devices, a combination of solar panels, external auxiliary batteries and charging pots, produced by Hatsuden Nabe, proved to be fitting for the scope of this field trip. The full hardware report is presented in appendix B.2, however, the focus of this chapter is on the software elements of the platform, and more specifically on the decision tree interfaces.

In terms of software, due to the secrecy of the project it was not possible to train more than four participants. These four key members, who were willing to collect poaching data, were the same ones that had created the icons in the first place, and were able to participate in the training and evaluation sessions. Given the limited resources and time in field, the research assistant did not have the opportunity to conduct rigid evaluations with each of the participants and comply with the pre-arranged evaluation protocol. Instead, following the training session, the four participants were handed the devices and the research assistant maintained an observational role, while asking them to perform each of the tasks from box 1. Also, because this was a first evaluation of the platform, no risks were taken and hence the data did not reflect actual poaching activity, but just the usability evaluation tasks and training sessions.

Hence, in terms of evaluation, this case study had to rely on the observational role of the research assistant and the anecdotal observations that he reported during the interview, as well as the analysis of the collected data in correlation with the app text logs.

According to the research assistant's observations, during the training and on the following evaluation, participants quickly grasped the concept of the decision tree and of pictorial icons representing observations. In general, the participants were satisfied and comfortable with the grid arrangement of the icons. They were not confused by the fact that some screens showed 6 square icons, such as in figure 6.4a on page 107, whereas others showed just 3 rectangular icons, as in figure 6.4b on the same page. Although participants suggested a number of improvements to the graphics to make them clearer and more easily recognisable, overall they could quickly work out what each icon represented. While black and white performed well,

Figure 6.6.: Mbendjele member making an observation. © *Jerome Lewis, ExCiteS group*

as it enhanced readability, there were some icons for which the Mbendjele asked to have colour added, mostly red.

Table 6.1.: Collected data.

Observations collected	427
Photos	129
Audio recordings	40
Average GPS accuracy	29.01m

As part of the training and testing, members of the Mbendjele collected a total of 427 observations, 151 photos and 40 audio recordings (table 6.1). Figure 6.6 shows one of the community members recording an observation, while figure 6.7 shows a distribution of data collected per day.

As noted, the prototype recorded each single interaction happening on the system. Analysing the logs of the training and usability sessions showed that participants required an average of *46.5* seconds (median 42 seconds) to perform a single observation. Further analysis on the logs was conducted and the preference of the various UI components was calculated. Figure 6.8 shows the popularity of the elements shown on a prototype screen such as icons, navigation buttons (back)

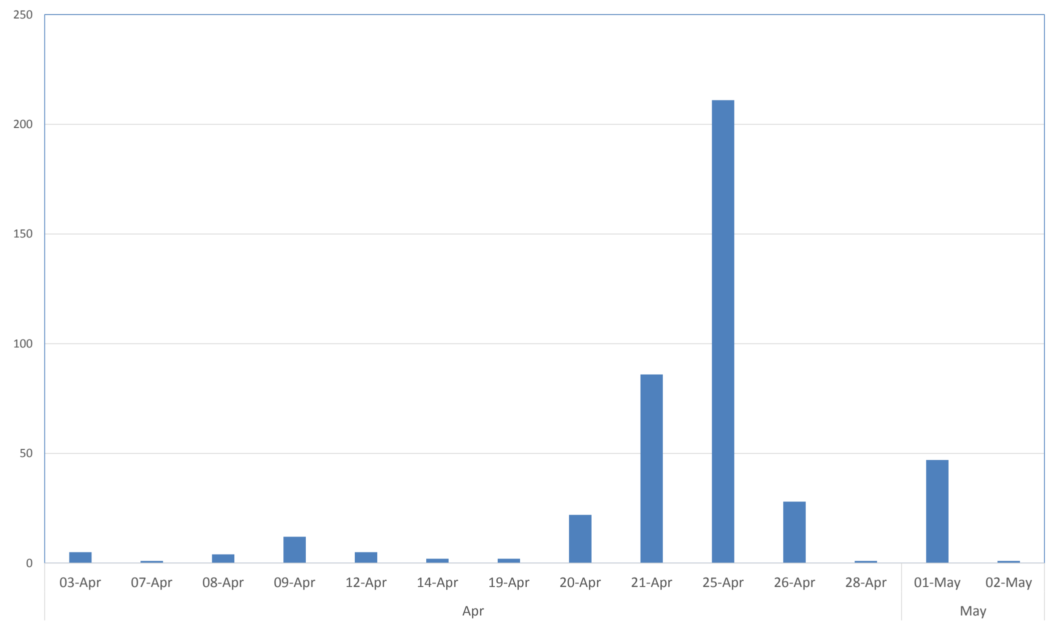


Figure 6.7.: Observations per day.

and the long-click interaction. For instance, 93.34% of participants' clicks were pictorial icons, 6.46% were the back button and 0.20% of their interactions was a long-click.

6.6 Discussion

The Anti-Poaching case study acted as a proof of concept and the first step towards the wider vision of implementing technological means for communities to capture their local environmental knowledge using scientifically accepted methods. The main purpose of this case study was to capture a list of requirements and identify the context to concretise this research. Understanding the context and the requirements could contribute towards research question RQ 2. Next, this case study provided the opportunity for an initial exploration of whether decision trees are appropriate for data capture, an thus explore the research question RQ 1.

In this section, the results of the case study are discussed in terms of the two research questions. The section starts with the discussion of RQ 2 as it is more general and leads to the discussion on RQ 1.

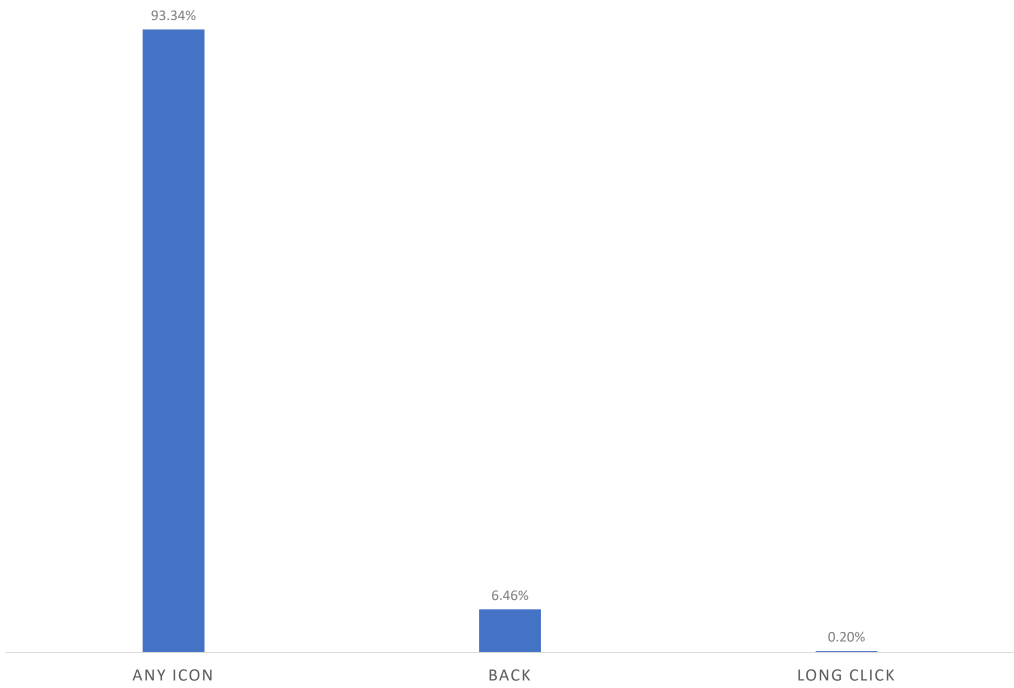


Figure 6.8.: Clicks per visual item.

6.6.1 RQ 2

The second research question of the thesis explored the challenges of designing, evaluating and deploying an ICT system for non-literate participants to capture TEK.

One of the early challenges that was identified, was the difficulty of finding and establishing collaborations that would include the opportunity for research. As noted in section 6.1, establishing collaborations with local stakeholders that are trusted by communities gives legitimacy to the project and is vital (Sein and Furuholt, 2009, 2012; Aal et al., 2014; Stevens et al., 2014; Therias et al., 2015). As a result, the success of a case study would also promote subsequent case studies, thus, opportunities for research activities. This in turn, requires the researchers to act as community facilitators, logistics planners, interface designers, software engineers, and ICT consultants in order to provide an integrated solution that would work under the local conditions.

Another challenge, that was identified in the early stages of the project, was the difficulty for a researcher to visit the research area in a short notice. As presented in section 3.2, there were plenty of restrictions in accessing the participants. This, in combination with other researchers suggesting that users in ICT4D contexts lack the skills to provide feedback and describe their requirements in terms of ICT systems (section 6.2), led to an alternative elicitation of requirements where a local expert was interviewed and a full prototype was developed based on that input and by examining similar literature.

It was clear, that this first list of requirements had a numbers of limitations and could be biased, since only one representative of the communities was employed to extract the requirements. That limitation would be addressed in subsequent case studies with more anthropologists being interviewed to provide a more representative sample, and field trips being organised for extracting requirements in field by observing and interviewing participants.

Finally, an open question was identified related to determining the appropriate logistic, social and financial conditions that would enable such projects to scale up and be sustainable over long periods of time. For instance, the fact that when the Mbendjele were introduced with the devices, they found alternative values such as use their screens as torches in the night, or record and playback their traditional music had to be considered. It is possible for the additional purposes to motivate users to better treat and care for the devices (recharging them on time etc.), but still further observation was necessary to determine whether and how that unintended usage should be curbed. It was expected that applying the same solutions in a variety of contexts would create opportunities to try out new concepts and answer open questions.

6.6.2 RQ 1

The first and primary research question of the thesis, explored the appropriateness of decision trees as an interaction mode for ICT systems for non-literate participants to capture TEK.

In terms of software, the prototype and the community's excitement acted as a technology demonstrator and verified the potential of the approach. Due to the secrecy of the project it was not possible to train and evaluate the software with more than four participants. However, from the first anecdotal observations and from log analysis, it seemed that the participants were trained quickly and grasped the concept of the decision tree and of pictorial icons representing observations.

However, there was a minor indication, from the log analysis, that participants did not favour the navigation button (back button) as the one presented in figure 6.4b. As illustrated in figure 6.8, participants clicked on any icon by 93.34%, while they clicked the back button only 6.46% out of the total clicks on the UI elements. There is also a 0.20% instances of long clicks, but these can only be regarded as accidental.

Prior to the field trip, it was hypothesised, that since the participants were just introduced to the UI, they would use the back button in many more occasions to explore the affordances of the UI and find the icons that they were looking for in the decision tree. This low interaction number on the back button could be explained in two different ways; either the participants were extremely confident in their decisions or it could indicate a minor navigation issue in regards to categories. However, since exact performance rates were not present, it was impossible to favour one of the two theories.

When the results of the analysis were discussed with the research assistant who conducted the evaluations, it was concluded that the prototype was lacking of a '*cancellation*' button, to allow participants to quickly cancel the current observation and return to the '*home*' screen (i.e. figure 6.4a on page 107), without the need of pressing the back button multiple times, which could be frustrating or confusing for the user in cases of deep trees with multiple levels. Next, the prototype was lacking a confirmation screen to signal to the participants that they reached the end of an observation and their action was needed to either save or discard the observation. These two missing elements, could explain the lack of use of the navigational icons.

Although at that stage the initial evaluation was conducted by a research assistant, it demonstrated that the hardware selected for the project was appropriate and the prototype worked as expected but it also resulted in helpful suggestions for further improvements, and amendments in the requirements, as presented in table B.4 (on page 259). However, the first field trip also revealed the need for the author to join the field trips. As mentioned above, the list of requirements had to be extended by taking into account more sources to increase the credibility of the list. In addition, the fact that the device logs presented a slightly different picture from the observations and reports of the research assistant, indicated that more structured usability evaluations had to take place.

Finally, the discussion with the participants, even through a proxy, also led to valuable feedback for improvements, mainly on the icons since some of the participants had suggestions on the drawings that could improve the clarity and comprehension. Some participants had suggestions on the structure of the decision tree and requested additional choices to the tree such as the option to report evidence of ivory stock or bush-meat etc., while others asked for the elimination of some choices i.e. removing the ambiguous icon for reporting a poacher's camp that was unclear whether the camp was occupied or not etc.

6.7 Summary

This chapter explored the endeavour to enable the Mbendjele hunter-gatherers in the Congo Basin rainforest to monitor and map the activities of commercial poachers in their area. The goal was to allow more effective control over poachers, and, moreover, to curb the harassment the Mbendjele suffered at the hands of corrupt 'eco-guards' (section 6.1).

Over the course of April 2012, a prototype was tested by the Mbendjele in the rainforest of RoC (section 6.5). The evaluation was conducted by a research assistant, due to the logistical and practical issues (with the lack of travel visa being the most important). As far as hardware was concerned, the results were promising, as the devices proved to be robust to withstand the dust and humidity of the forest, as well as the treatment by the participants.

In terms of software, due to the secrecy of the project the prototype was introduced to and evaluated with only four participants (section 6.5). However, from the first anecdotal observations reported back by the research assistant, it seemed like the participants did get the training quickly and grasped the concept of the decision tree and of pictorial icons representing observations. However, a log analysis revealed some contradictory results, with participants favouring pictorial icons to navigational buttons (section 6.5.3).

The initial evaluation demonstrated that the prototype worked but it also resulted in helpful suggestions for further improvements in the icons, the navigation and the functionalities (section 6.5.3). Finally, it was clearly understood that in a field trip was necessary to further amend the requirements list and explore the contradictory results between observations and device logs.

7 Case study 2: Participatory monitoring of logging

> *When the last tree has been cut down, the last fish caught, the last river poisoned, only then will we realize that one cannot eat money.*
>
> — **Cree Indian prophecy** (Potocnik, 2010)

This chapter[1] describes the approach for delivering ICT tools to support remote communities to participate in TEK gathering. Most specifically this chapter describes the collaboration between ExCiteS and Forests Monitor, an international NGO, to develop and evaluate a tool, that would enable the local people to participate in the monitoring of socio-economic impacts of logging activities. In terms of this research, this case study endeavours to evaluate the usability of decision trees for collecting data, in this context, and therefore answer the two research questions, as defined in chapter 4.

The first two sections (7.1, 7.2), draw the social context of the case stydy. In section 7.3, the list of functional requirements for the ICT platform are presented along with the methodology employed to amend the list, while section 7.4 briefly describes the development of *Sapelli*, a new, more flexible platform data collection platform. Then, section 7.5 presents the evaluation of the platform by the local communities, while section 7.6 discusses the results of the evaluation and the methods employed.

[1]Parts of this chapter are published in:

a) Stevens, Matthias, Michalis Vitos, Julia Altenbuchner, Gillian Conquest, Jerome Lewis and Muki Haklay (2013a). “Introducing Sapelli: a mobile data collection platform for non-literate users”. In: *Proceedings of the 4th Annual Symposium on Computing for Development*. ACM DEV-4 ’13. Association for Computing Machinery (ACM). ISBN: http://id.crossref.org/isbn/9781450325585. DOI: 10.1145/2537052.2537069.

b) Stevens, Matthias, Michalis Vitos, Julia Altenbuchner, Gillian Conquest, Jerome Lewis and Muki Haklay (2014). “Taking Participatory Citizen Science to Extremes”. In: *IEEE Pervasive Computing* 13.2, pp. 20–29. ISSN: 1536-1268. DOI: 10.1109/MPRV.2014.37URL: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=6818498.

7.1 Social context

As introduced in section 3.1, the Congo Basin hosts numerous settled and forest communities that highly depend on the rainforest for their livelihood. However, current conservation and natural resource management efforts, supported by international organisations such as the WCS, the WWF or other NGOs, often involve draconian measures which disenfranchise locals (Ichikawa, 2014). The overwhelming tendency in Central Africa since the 1990s has been to establish protected areas that exclude local people, or restrict their access, in parallel with the aggressive promotion of industrial resource extraction in adjoining areas (Brockington et al., 2006; West et al., 2006; Lewis, 2008).

Although the Congo Basin is internationally recognised as a unique biodiversity hotspot that has a direct impact on climate change, the forestry and resources extraction sectors are rapidly growing (Lewis, 2012b). The promotion of private sector investment in order to meet adjustment targets and the MDGs in combination with the high demand of tropical timber, led to massive increase of the forestry sector (Lewis, 2012b). During the last two decades, the national legal systems of the Congo Basin's countries have been reshaped to encourage international investments to control and manage forest territories regardless of the local forest peoples' needs, for instance Cameroon in 1994, Republic of the Congo (Congo-Brazzaville) in 2000, Gabon in 2001 and DRC in 2002 (Lewis, 2012b). The current political status quo divides the forest into PFEs and NPFEs. The permanent areas are either established as national parks and protected areas that exclude local forest people, or they are divided as logging and mining concessions. In Republic of the Congo for example, all forested areas are considered governmental property and are divided into various-size concessions that are leased to private logging companies for 10-15 years (Conquest, 2014). The remaining non-permanent areas are used primarily by local settled communities, leading forest peoples in vulnerable positions (Lewis, 2012b; Eisen et al., 2014). As logging roads open up increasingly remote regions to commercial activities, more and more of the forest's resources are drawn out onto (inter)national trade networks and forest people watch their resource base diminishing.

In addition, the Congo Basin governments do not often have the capacity to develop and maintain local infrastructure in the remote areas of the rainforest. Instead, the State includes a series of social responsibility agreements (referred to as '*cahier des charges*') as part of their contracts with logging companies. These agreements include the active development and maintenance of local facilities such as roads, bridges, schools, hospitals and other activities normally undertaken by the government (Lewis, 2002; Seyler et al., 2010; Conquest, 2014; Lescuyer et al., 2014). As a result, the logging sector dominates the regional economy, and private logging companies can have more direct impact on local people's lives than the government (Lewis, 2002; Conquest, 2014).

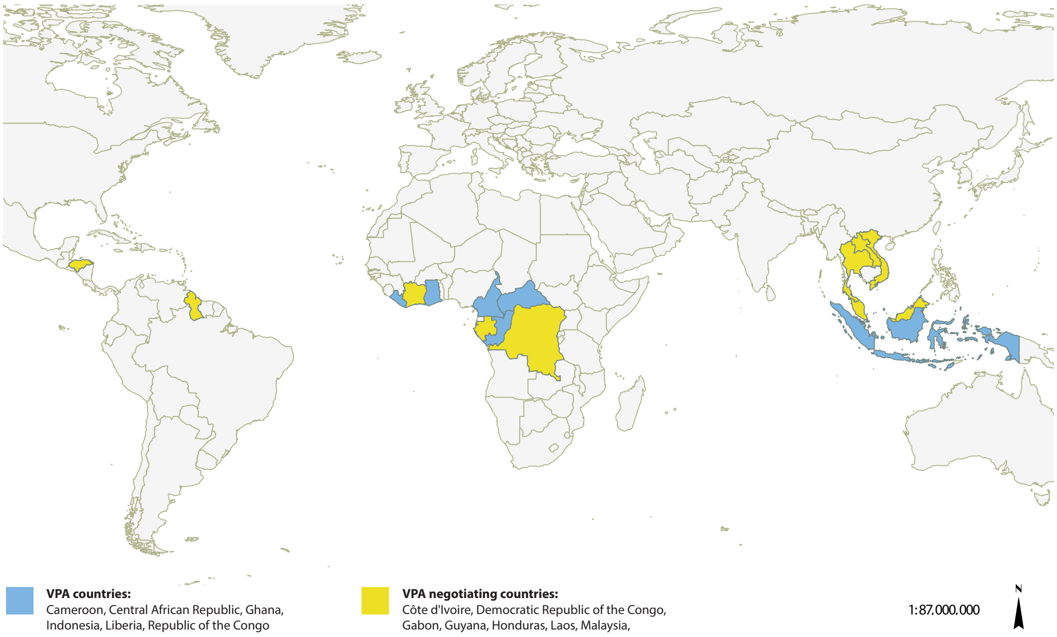


Figure 7.1.: Countries that have signed a Voluntary Partnership Agreement (VPA) with EU. *Data from FLEGT.*

It is noteworthy to mention that the Republic of the Congo is one of the ten countries in the world where local communities and indigenous groups do not have any formal ownership of the forest and there are no governmental managed forest areas reserved for such groups (Humphreys, 2008). This means that local indigenous populations, especially hunter-gatherers are rarely involved in the management of the areas on which they depend. However, the legal context is under revision since in May 2010, the Republic of the Congo was the first Congo Basin country to sign a VPA with EU under the EU's FLEGT (European Union, 2015). The FLEGT Action Plan is a EU endeavour to address illegal logging and the socio-economic consequences it has on the environment and local communities in the affected areas (European Union, 2015), and is ensured by signing a VPA, which is a mutual agreement between the EU and a timber-exporting country outside the EU. Under the VPA agreement, the signing country agrees to export only timber from legal sources to EU and the EU agrees to assist the partner county to stop illegal logging and improve forest governance (figure 7.1). The VPA empowers local indigenous peoples and strengthens their community rights. The importance of this agreement is reflected by '*Principle 3*' of the EU ROC VPA which states:

> *The [logging] company involves civil society and local and indigenous populations in the management of its concession and respects the rights of these*

populations and workers. The company has a mechanism for functional dialogue between the stakeholders with respect to the sustainable management of its concession (European Union, 2011, p. 141).

Amongst others, the VPA includes rules that describe the active involvement of communities in the management of the forest concession. According to the agreement, logging companies should: sufficiently inform local and indigenous communities regarding their rights and the management of the forestry concession (Principle 3.1.2); respect their rights, customs and practices according to national and international legislation (Principle 3.2); compensate local and indigenous populations according to relevant legislation in cases of the company damaging their properties or resources (Principle 3.2.3) and include mechanisms for on-going dialogue and dispute resolution with communities (Principle 3.3).

7.2 Participatory monitoring of logging

In 2007, the Ministry of Forest Economy (MEF) of Republic of the Congo established the *Independent Monitoring of Forest Law Enforcement Systems and Governance (IM-FLEG)*, a project aiming to create methods and tools to independently monitor logging activities and improve forest governance as a preamble to the VPA agreement (Forests Monitor, 2016). Forests Monitor, an international NGO focusing on transparency and accountability of the forestry sector, partnered with Resource Extraction Monitoring (REM), also an international NGO specialising in monitoring of law enforcement and natural resource extraction, to implement the first phase of IM-FLEG (Forests Monitor, 2016; REM, 2016). During a 45 months' period of the first phase, the two NGOs were focusing on governance of forest law enforcement and on detection and suppression of forest infractions.

In 2010, Forests Monitor and REM, were assigned with a 3-year EU-funded project to continue on the implementation of the IM-FLEG, and focus on building local capacity by transferring skills and knowledge of conducting independent monitoring to local Civil Society Organizations (CSOs), such as *Cercle d'Appui à la Gestion Durable des Forêts* [Circle of Support for Sustainable Forest Management] (CAGDF), that would form the local independent forestry watchdog in Republic of the Congo and ensure the implementation of the newly signed VPA.

In 2012, Forests Monitor collaborated with ExCiteS to design and deploy a pilot ICT system that would enable local forest communities in Republic of Congo to participate in monitoring the socio-economic impact of logging activities in their lives. By giving the local population the means to directly communicate with IM-

FLEG, Forests Monitor aimed to collect data and evidence on the VPA implementation, support local communities to claim their rights according to the VPA legislation and finally increase forestry transparency by publishing the data regarding the logging companies' compliance to the VPA to the web portal of World Resources Institute (WRI).

In terms of this individual research, the collaboration between Forests Monitor and ExCiteS, was a significant opportunity that gave access to a case study to further evaluate whether decision trees could be employed to allow participants to collect logging data and therefore work towards answering research question RQ 1, but also explore the challenges in such an endeavour (research question RQ 2). In addition, having a local partner on the ground allowed the author to participate in a field trip to conduct field evaluation and usability studies, capture requirements and improve the software following a UCD approach. For IM-FLEG the intention was to explore the feasibility of an ICT based, sustainable monitoring system for the forestry sector nationwide in Republic of the Congo, based on the ExCiteS approach. The rest of the chapter covers this collaboration with IM-FLEG by describing the pilot deployment and the field evaluation of the system.

7.3 Requirements Analysis

As presented in chapter 6, the initial list of requirements was drafted after a series of interviews with an anthropologist and by reviewing the similar platforms in the literature (section 6.2). Following the evaluation of the first prototype in field, the list of requirements was amended and extended (section 6.5). As discussed in section 6.6, this list of requirements had the risk of being biased, as it was primarily based on the input of one anthropologist.

To mitigate that issue, on this second case study, the requirements were reviewed, amended and extend based on four alternative sources. (a) Initially, the requirements were amended based on the input of the research assistant, who executed the evaluation in the previous prototype. (b) Next, given the collaboration with Forests Monitor, the list was further extended based on discussions that the author had with representatives from the NGO. (c) Later, another anthropologist was consulted to validate whether the captured requirements reflected the context of use and the actual needs of participants. (d) Finally, a research trip was organised, for the author to personally observe the context and requirements first hand.

Table F.1, in appendix F, presents the product of the above process, that led to a reviewed and amended list of requirements that the new platform had to meet.

In a summary, the new functional requirements of the platform, asked for a data collection tool that would enable non-literate or semi-literate participants to collect data on logging. The platform required to operate on handheld devices, support pictorial decision trees and compliment each observation with GPS coordinates, photos and audio recordings. The next section, moves in a brief description of the development of the new prototype that tried to match all the requirements.

7.4 Prototype development

The focus of this chapter is on the usability evaluation of decision trees and the interaction challenges that were identified by observing indigenous community members using the bespoke software, as will be discussed later on. However, before describing the work exploring the two research questions of the thesis, it is necessary to briefly describe the new prototype that was developed to meet the identified requirements.

As noted in the previous chapter, the first prototype was based on the open-source project ODK. However, after the first field evaluation and taking into account the new requirements, it was fairly soon obvious that ODK was unsuitable for the wider vision. The main drawback was that ODK, due to its XForms-based survey description format, was not well suited for hierarchical data input flows. Even relatively simple and compact decision trees require extremely verbose and complicated XForms code to be written. Clearly that limited the ability to flexibly adapt decision trees to changing local circumstances (e.g. in the field), as well as to reconfigure them for other contexts. Another requirement which ODK did not satisfy was the ability to transmit data to a central server in an autonomous and multi-modal fashion. Appendix F.2 describes all the limitations in full detail.

Since no open source platform, satisfied these requirements, it led to the development of a new, data collection and transmission platform to support the on-going projects related to poaching and logging, as well as future participatory monitoring and mapping projects. The platform was named ***Sapelli*** after the endangered *sapelli* tree (Entandrophragma cylindricum) which is important to Pygmy communities.

Figure 7.2 shows the overall architecture of the platform, which consisted of 4 main components:

- ***Sapelli Collector:*** a data collection app, with integrated data sending service for Android devices;

- ***Sapelli Relay:*** an Android app designed to receive and forward SMS messages;
- ***Sapelli Server:*** a web server application to receive and store data; and
- ***Sapelli Launcher:*** an Android *home* replacement that provides a text-free app launching interface.

The platform was collaboratively designed and developed within ExCiteS, with the author having a major contribution in the process and being primarily responsible for the UI elements of the platform, the transmission mechanisms and the Sapelli Launcher (see appendix F.3). However, the focus of this chapter is not on the technical aspects, thus it briefly describes the main components of the tool.

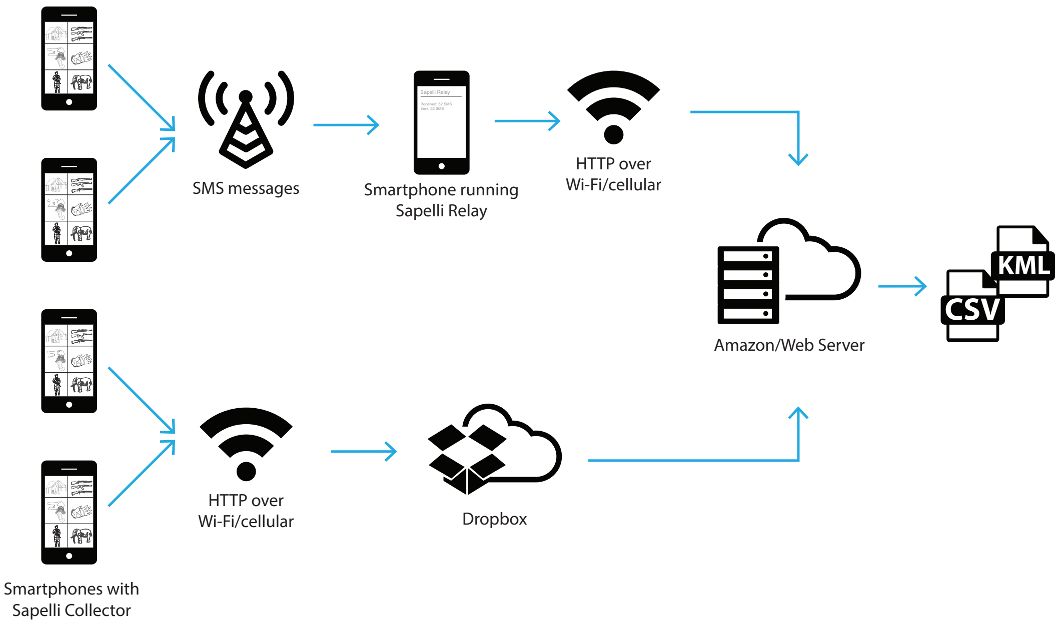


Figure 7.2.: Sapelli Platform Architecture.

The *Sapelli Collector* and *Launcher* were vital components for realising research question RQ 1, thus are briefly described in the following sections 7.4.1 and 7.4.2. The *Sapelli Relay* and *Server*, despite being critical components from an ICT4D perspective, are out of the scope of this chapter and therefore presented in appendix F.3.3.

7.4.1 Sapelli Collector

The *Sapelli Collector v1* was the Android app of the Sapelli platform that enabled data collection through pictorial only interfaces. In this section an overview of the package structure and the UIs presented to participants are presented.

Sapelli Package Description

In order for Sapelli to be generic enough and to be used in other contexts, projects were intentionally separated from the actual mobile data collection application. The Sapelli Collector could retrieve, parse and present information from a Sapelli project file containing surveys described in a bespoke XML-based language which was designed to be highly readable and simple enough for anyone with basic computer skills, but no prior programming experience, to learn in a few hours. Therefore, the application could be used in combination with different projects in any data collection scenario to deploy a virtually infinite variety of data collection surveys.

Sapelli projects were simply ZIP files renamed to have a '*.sapelli*' or '*.sap*' extension and consisted of the project description (as an XML file) bundled with any other resources that were required for data collection, such as pictorial icons used to render the user interface. The project file were fed to Sapelli Collector which was responsible for parsing the XML file and arranging the pictorial icons into a grid on the screen depending on the options.

For an extensive description of the Sapelli XML elements and the different ways of using them, please refer to appendix F.3.2. This section moves on the user interface, operating on decision trees, that Sapelli offered to participants.

User Interface and Navigation

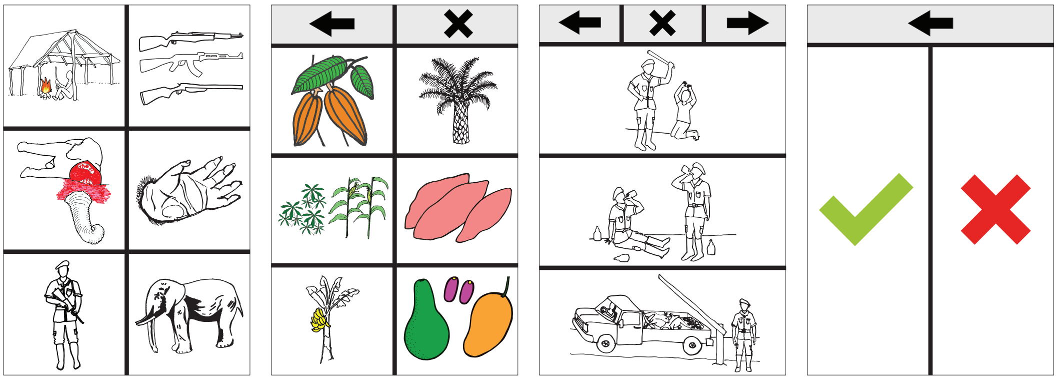
Sapelli was designed to produce fullscreen, minimalistic, entirely graphical interface with icons arranged in a grid, as in the Anti-Poaching prototype described in the previous chapter. For instance, figure 7.3, shows various screens of an icon-based decision tree produced by Sapelli. As in the first prototype, the UI could be navigated by tapping on one of the icons on the touch-screen, and then presented with a new, more specific set of choices. At every level except the top (root level), a back button allowed users to go back one level in case they made a mistake, and a cancel buttons allowed them to go directly to the home screen (see figure 7.3b).

However, the first implementation of Sapelli offered some new features that were absent in the ODK-based version of the previous prototype. These features were the result of the interviews with the research assistant, after his field trip in RoC, and the log analysis (see section 6.5).

First of all, for the navigational purposes, an extra button for cancelling the observation next to the back arrow was implemented (e.g. figure 7.3b and figure 7.3c).

The function of this button was to quickly cancel an observation and return to the '*home*' screen (i.e. figure 7.3a), without having to press the back button multiple times – which in cases of trees with multiple levels becomes frustrating for the user. This could explain why participants seemed to favour the icons over navigational items (see section 6.6). Whether the back and the cancel buttons were present in a project could be defined in the Sapelli's XML file by assign the attributes '*showBack*' and '*showCancel*' to true or false. This enabled project designers to easily explore different options and cater the needs of diverse participating groups.

Another important element was the addition of a confirmation screen as shown in figure 7.3d. This screen signalled to the participants that they reached at the end of an observation and by selecting the tick (✔) they could accept and save the observation or they could cancel it by pressing the cross icon (✖). Crosses and ticks were selected since they were already used in similar ICT4D projects without any reports of issues (Liebenberg et al., 1999; Lewis, 2007, 2012b; Liebenberg et al., 2017). At the end of the observation a sound was played or the phone vibrated to feedback to the user the successful completion of the observation. Project designers could decide whether the device was vibrating or the sound was played after the confirmation by modifying the project's XML file.



(a) First screen of decision tree | (b) Navigation buttons | (c) Optional button | (d) Confirmation screen

Figure 7.3.: User interfaces produced by Sapelli.

Finally, one of the elements added was the choice to have optional fields that the participant could skip without providing an answer. The optionality could be defined on the XML level of the project and a forward arrow was drawn on the UI to enable avoiding of the particular screen and the implied question. For instance, figure 7.3c, allows participants to report the inappropriate behaviour of Eco-guards in their area. Users can point out that an Eco-guard was identified to abuse village members, been drunk on duty or been corrupted. On the navigation level though, participants could select to go back, cancel the observation or move forward without answering this question.

7.4.2 Sapelli Launcher

A text-free application can still be difficult to use for low or non-literate participants when it runs on an operating system with a complicated, text-heavy interface such as Android. Whenever the '*Home*' button of the device is pressed, the user is transferred away from the data collection application to the system's main UI, which differs depending on the Android version of the OS and the manufacturer of the device. Different manufacturers are implementing their own personalised UI theme for Android to differentiate themselves from the competition (Mitroff, 2014). Figure 7.4 shows the '*Home*' UI for three different vendors. Pressing the home button, and going to the home screen, could be a very frustrating and confusing experience for non-literate participants, that could negatively influence their performance with pictorial interfaces, thus having an impact on the results regarding research question RQ 1.

(a) Stock UI for Android Lollipop

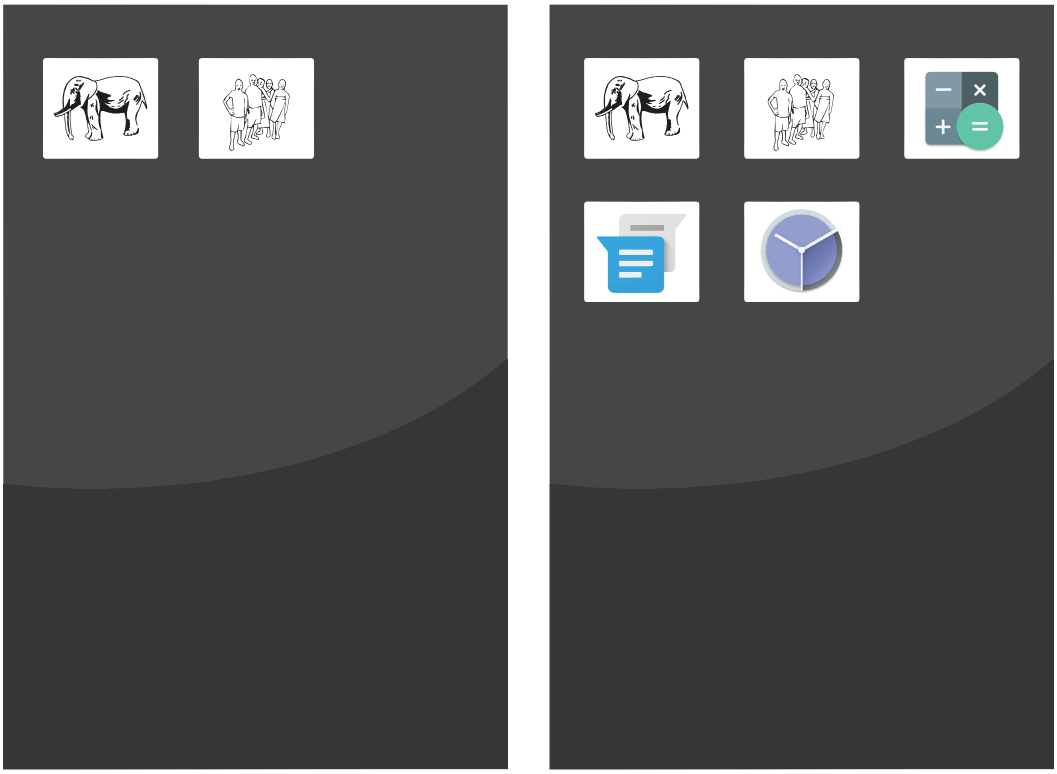
(b) Samsung UI for Android Lollipop

(c) HTC UI for Android Lollipop

Figure 7.4.: Different versions of Android's home screen. *Image a © Android; Image b © Samsung; Image c © HTC*

To tackle this issue, the '*Sapelli Launcher*' was developed. An application that could be installed on any Android-based device and replace the complicated, standard Android UI with a restricted, text-free app launching interface. This interface only showed icons for a set of allowed apps, which could be tailored based on project requirements and user abilities. Sapelli Collector was fully compatible with the Launcher and shortcuts that led to specific projects instead of the main screen of the Collector app, could be created. For instance, figure 7.5a is demonstrating the main screen of the Launcher containing only two icons, both shortcuts for data collection projects. The first icon leads to the Anti-Poaching project, described in the previous chapter, while the second icon leads to participatory monitoring of logging project.

Besides allowing access only to data collection, the Launcher could also provide access to other system applications depending on the users' level of literacy or the needs of a specific project. For example, in figure 7.5b, participants have also access to the calculator, to the messaging app and to the clock, along with the two Sapelli Collector projects.



(a) Home screen with access to two Sapelli projects

(b) Home screen with access to projects, calculator, SMS and clock

Figure 7.5.: Different home screen based on the allowed applications.

The Sapelli Launcher also had a number of other functionalities and features, that are out of the scope of this chapter to discuss. For a more detailed description, refer to appendix F.3.4.

7.5 Evaluation

As in the previous case study, in order to evaluate the feasibility of the approach, the different technological, methodological and software elements of the approach had to be tested and evaluated. The evaluation was again done in two stages, initially the prototype was tested in London by conducting a cognitive walkthrough (section 7.5.1), and later was tested in field by the different communities (section 7.5.2).

7.5.1 Cognitive Walkthrough

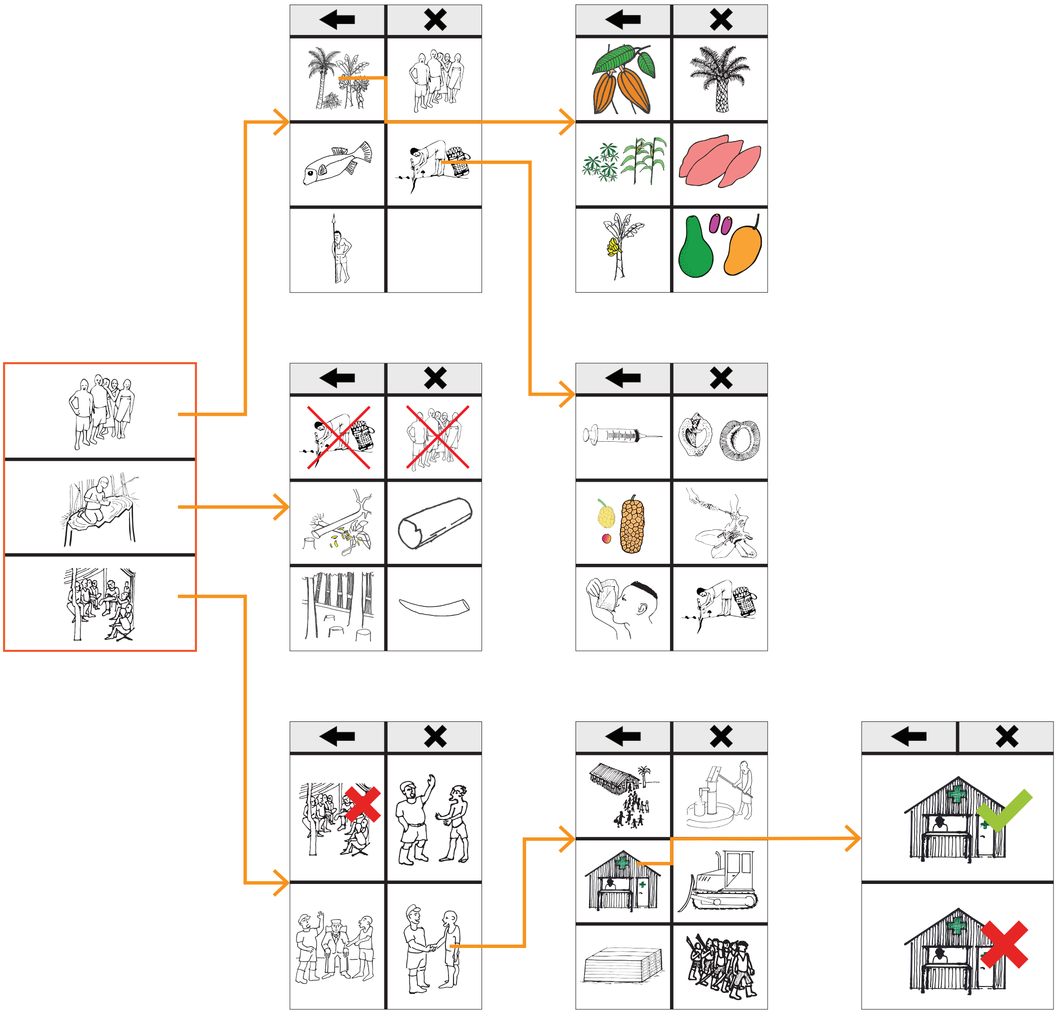


Figure 7.6.: UI representation of the decision tree designed in collaboration with Forests Monitor, CAGDF and local communities.

Following discussions and interviews with Forests Monitor, an initial decision tree was designed and coded into the Sapelli program. The structure of the decision tree and the coding into Sapelli was conducted by the author, while the design of the icons was performed by other ExCiteS members. The first decision tree consisted of 61 final leaf choices and was spread over 5 levels (see page 344 for a figure of the decision tree). Figure 7.6, illustrates parts of the decision tree, which started from a home screen where the participants had three distinct options to (a) geo-reference their local resources; (b) record evidence of illegal activities such as damaged or destroyed resources by the logging company or poaching activities in their area; (c) record whether consultations with the logging company had taken place and their outcome i.e. whether *cahier des charges* had been achieved. This prototype decision tree could act as a starting point in the discussion with local communities in order to identify what the community considered important for capturing. Based on input from the communities, that decision tree later changed to the one illustrated in page 346. However, this was part of the work of the anthropologists of ExCiteS and of the scope of this thesis to discuss here.

As in the previous case study (section 6.5.1), a *cognitive walkthrough* was performed before the field trip to ensure the basic usability of the prototype, in a low-cost, fast and effective method. Once again, cognitive walkthroughs are challenging when the end users are so different and instead an alternative version of cognitive walkthrough was applied. This time, two field experts (in this case anthropologists) participated in the walkthrough and acted as a proxy for the end users to identify major usability hurdles. For this reason, the anthropologists were presented with the prototype and with a set of goals to perform (i.e. record the position of your village), subdivided in a number of tasks (box 2). For each task, they had to answer a set of usability questions such as '*Will the user know what to do?*', '*Will the user see how to do it?*' and '*Will the user understand the received feedback?*'.

Box 2 Usability Tasks

- **Task 1**

Imagine that you take part in a participatory mapping exercise and that you want to use the *Sapelli* system to map your local resources.

Subtask 1: Suppose that you start at the centre of your *village*, please take a point of the village to map it.
Subtask 2: Suppose that you walk and find an important *palm tree* for the community, use the system to map it and protect it from logging.
Subtask 3: Suppose that you walk and find an important *banana tree* for the community, use the system to map it and protect it from logging.
Subtask 4: Suppose that you walk and find an important *medicinal tree* for the community, use the system to map it and protect it from logging.

- **Task 2**

Suppose that you walk into the forest and you find out that the logging company has abandoned a log they felled. How would you document that without taking any photos or audio recordings?

- **Task 3**
Suppose that you walk into the forest and you find out that an artisan logger has abandoned a log they felled. How would you document that and take a photo to inform the local authorities?

- **Task 4**
Suppose that you are having a dispute with the logging company because they caused damage to your palm trees. The company is refusing to recognise the damage. How would you document that and provide photos of the damage, along with an audio recording where you explain in detail what the problem is?

- **Task 5**
Suppose that you had a consultation with the logging company and they agreed to build a water pump for the community. However, after 6 months, the pump has not been built. How can you document that and provide an audio recording explaining the situation?

Based on the evaluation of the cognitive walkthrough, icons were changed and the structure of the decision tree was adapted. When in field, another cognitive walkthrough was conducted, but this time with one member of the Forests Monitor, to ensure that decision tree covered all the discussed elements.

7.5.2 Field evaluation

Then, when satisfied with the outcome of the cognitive walkthrough, the prototype platform was tested in the field by different communities. The field evaluation was part of a larger ExCiteS field visit that endeavoured to evaluate different aspectes of the technological and methodological approach. This thesis will briefly describe the research mission for the reader to understand the context, but it will focus only on the part of the field evaluation that attempted to answer research questions RQ 1 and RQ 2.

In the spring of 2013, an ExCiteS research team, composed of anthropologists, computer scientists and GIS experts, travelled to the RoC for 6 weeks. Working closely with representatives of Forests Monitor, REM and CAGDF, eight forest communities in the Sangha and Likouala departments in the north of Congo-Brazzaville, located in concessions under the control of three different logging companies, were visited. Members of the anthropology team were present throughout the duration of the trip. The presence of anthropologists was crucial to the engagement of local communities and led to discussions on the communities' willingness to participate and redefine the key data to be collected, following an FPIC process as described in (Lewis and Nkuintchua, 2012; Stevens et al., 2014).

In terms of this individual research, the author had the opportunity to visit four local communities (table 7.1), and (a) conduct field observations to understand the context and amend the requirements list, (b) conduct observations in regards to the usability of decision trees and finally (c) conduct structured usability trials followed by interviews.

Table 7.1.: Communities visited in field evaluation ordered by date of visit.

Community	Ethnic groups	Visit length
Longa	Pygmy (Mbendjele)	1 day
Sembola	Pygmy (Mbendjele)	1 day
Gbagbali	Pygmy (Mbendjele)	1 day
Attention	Bantu (Bakwele) and Pygmy (Mikaya & Baluma)	1 day

The field evaluation, related to this individual research, was composed of two distinct methods, (a) an ethnographic approach of observing participants while they were introduced to the Sapelli platform by anthropologists and NGO representatives, and (b) structured usability evaluations with 30 participants and interviews. Both methods are presented in the rest of the section.

Participants observation

As noted, the evaluation conducted for this research, was part of a wider ExCiteS field trip, and the participants observation took place as part of the ExCiteS introduction and training. The approach outlined was primarily the focus of the anthropologists and is described in Stevens et al. (2014). However, it was an important aspect of the evaluation process for this research and it is noteworthy to briefly describe here. As illustrated in figure 7.7, the process involved (1) discussion with the community in order to agree on the collected data and define the icons and structures, (2) train participants on the icons with the assistance of printed flashcards (figure 7.8a), (3) train participants on how to use the smartphones and the Sapelli software (figure 7.8b), and finally (4) run mapping sessions in the nearby area for participants to apply the new knowledge (figure 7.8c). This was an iterative process that aimed to improve the icons and the structure of the decision tree.

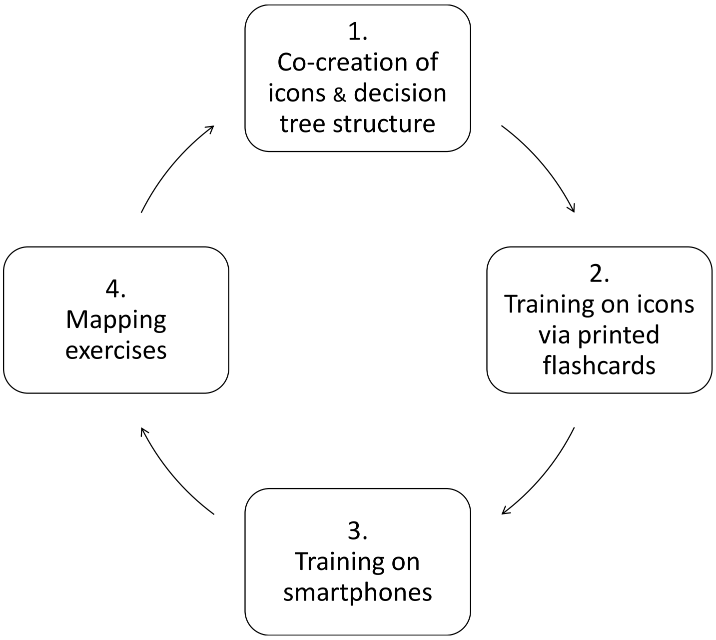


Figure 7.7.: Training and introduction steps.

(a) Training via flashcards **(b)** Training session **(c)** Mapping session

Figure 7.8.: Training and mapping sessions. © *Jerome Lewis, ExCiteS group*

In terms of this research, by the time the author joined the field trip, the decision tree structure and icons were finalised (see page 346), thus only steps 2-4 were followed with subsequent communities. Within that context, this research followed an ethnographic approach of observing the process for steps 2-4, with a focus on participants and their interaction with the ICT system in four communities as illustrated in table 7.1. Given that this was the first encounter with the field and the communities, it was preferable to act as a participant observer during the introduction and training of Sapelli, and during the mapping exercises in the nearby forest. After step 4 was completed, a structured usability evaluation and semi-structured interviews were then conducted, in each of the communities, as described in the next section.

Regarding the field observation, as Dix et al. (2003) suggest, during field observations, the researcher should stay almost invisible and as unobtrusive as possible. Hence, the author tried to be as unobtrusive as possible during steps 2-4 and focus on observing the interactions between people and the technology to understand how participants think, work and operate in order to identify usability issues and hurdles. During the observing process, all feedback was noted and the sessions were video-recorded for later analysis. The observations took place in four communities, where 192 participants (106 males, 86 females) were introduced to Sapelli, through training sessions and mapping exercises.

Structured Usability Evaluations

As noted, following the final step of the ExCiteS training, the participants were introduced to more structured usability evaluations to evaluate the effectiveness of the decision trees (research question RQ 1) on the one hand, and endeavour to establish a usability evaluation protocol that would explore the challenges on the other (research question RQ 2).

The evaluation plan included the usability tasks that were used in the cognitive walkthrough (box 1). These tasks were composed of multiple *scenario tasks* of different level and difficulty in order to quantify the efficiency (how much time users spent on a task and in how many steps they accomplish the given goal), the accuracy (the percentage of correct tasks in relation to the total tasks) and finally observe the emotional response (how do the users feel after the completion of each task) of the participating users.

Thirty adult participants (16 males, 14 females) took part in the study and they were selected on a voluntary basis on the day of the trials. The tasks were presented to participants as mini stories and they were asked to use the application to take action depending on the scenario (the detailed list of tasks is listed in box 2). Some of the tasks included simple goals such as recording the location of the village and the location of important local resources (palm trees, banana trees, etc.). As the tasks progressed in difficulty, participants were asked to augment the location data with photos or audio recordings depending on the question. The questions were formulated in such a way as to test users' ability to judge in which situations it was appropriate to take a photo, record audio, or do neither. For the final task participants were asked to use the app to its full extent (including appropriate use of audio/photo), for instance to document a hypothetical situation in which the logging company had not delivered on a previously agreed upon compensation. Following completion of the tasks, unstructured interviews took place with the participants to elicit feedback on the software and any problems that they encountered. Finally, each participant was compensated with XAF 1,000 (approximately £1.4) for their time and effort.

7.5.3 Results

This section presents the results of the evaluation.

Participants observation

Participant observation revealed that the interaction with the devices and more precisely the touchscreens proved challenging and frustrating for some people. Participants were unsure on how long they had to press on an icon and tended to perform a long-click rather than a short tap. In other cases, the short delay between a successful input and the appearance of the next screen also caused confusion. Participants assuming that their tap was not registered, tapped twice or more times on the same spot resulting in clicking on icons on the subsequent screen and navigating deeper on the decision tree by accident. To solve that, while in the field and following a rapid iteration development cycle, a short waiting animation to show that the tap has been successful and the new screen will appear shortly was introduced (figure 7.9). This was introduced after visiting the second community and was well received by participants as the same issue was not observed any more on the last two communities.

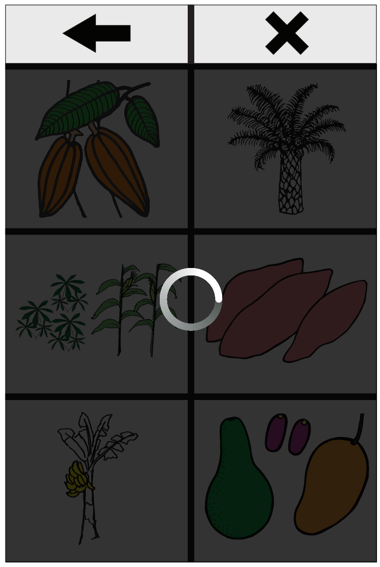


Figure 7.9.: Waiting animation.

Another important observation was the fact that interface navigation and the understanding of certain icons were hampered by the fact that common symbolic or metaphorical conventions (e.g. arrows [🡐], crosses [✖], ticks [✔], the use of green and red to respectively signify positive and negative connotations) were unknown or interpreted differently. Although, previous literature suggested that these could be employed in this scenario, participants seemed puzzled by their meaning. At a more general level, although participants co-designed the icons and were involved in the arrangement of the decision tree, they seemed to have trouble grasping the overall hierarchical structure and how to navigate through it using forward and backward steps, while there were indications of a possible correlation between the amount of trouble users had and the depth of the hierarchy were noticed.

Since the icons were co-designed with the community, the majority of them were easily recognised, however, it was observed that the interpretation of some icons caused major challenges due to the way that those particular icons were used. Depending on the drawing, and the level of the decision tree that they were presented, the icons were used in a literal, categorical or metaphorical use.

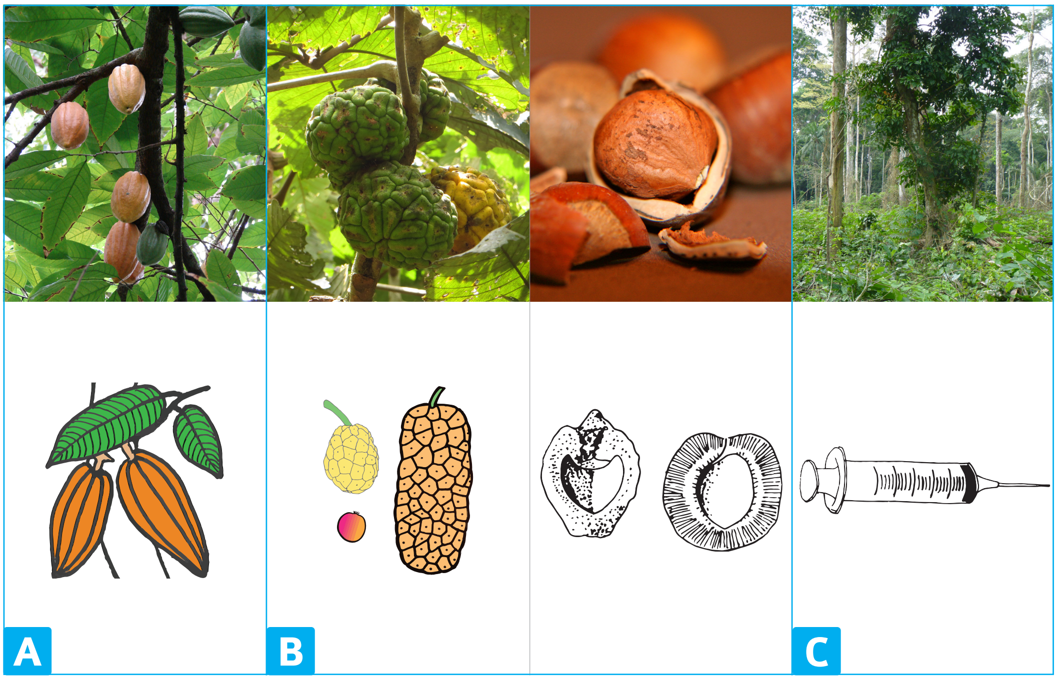


Figure 7.10.: Examples of pictorial icon categories: (a) literal use (b) categorical use (c) metaphorical use. *Cacao fruit* 🅭 *Forest and Kim Starr, used under CC BY 2.0; Forest Fruit © Matthias Stevens, ExCiteS group; Nuts* 🅭 *Kate Ter Haar, used under CC BY 2.0; Tree © Michalis Vitos, ExCiteS group;*

While most icons were designed to be interpreted literally, for instance the drawing of a cacao tree means explicitly the recording of a cacao tree, others were representing categories, which proved to be more challenging (figure 7.10). In Western societies it is common to use an example to refer to a category, e.g. an *apple* to represent the category '*fruit*'. Yet during the training and mapping sessions it became clear that category examples were often interpreted literally. For people whose livelihoods depend on the correct identification of a vast array of plants, fruits and animals, the accuracy of individual drawings was considered very important and led to a literal interpretation (figure 7.10).

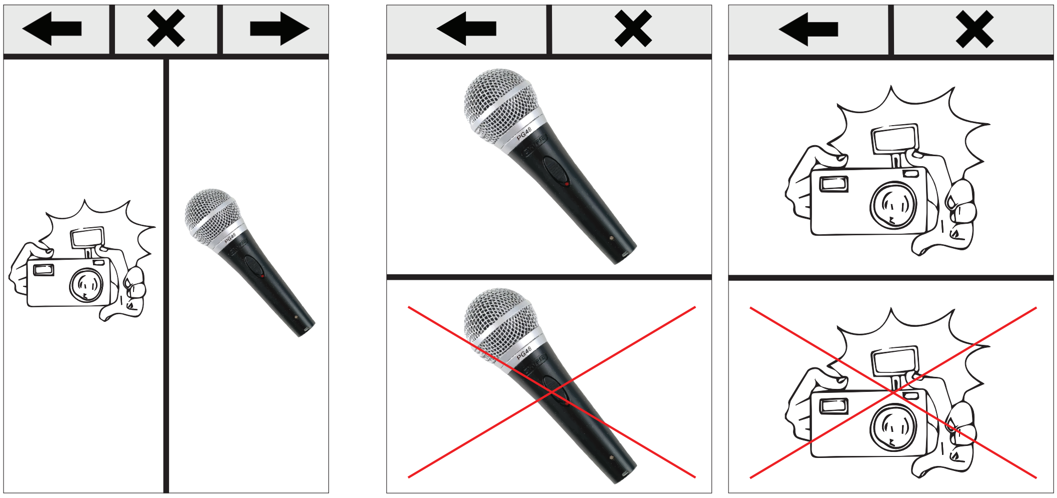
In some cases, these categorical icons occurred as a final choice, but more often they were used at the top or intermediary levels of the decision tree. In the former case this usually meant there was no need for further detail. For example, a drawing of a particular kind of wild fruit might represent *any* wild fruit, without a need to record which kind (figure 7.10). In the latter case, the icon typically summarised a set of possibilities that the user could choose from in the next screen. For instance, a drawing of a specific game species might represent the concept of hunting, and tapping it would then take the user to a screen offering a choice between multiple icons, each representing a particular game species, including the species that was taken to represent the category. Often this also meant the same icon occurred as both an intermediate category and a specific final answer. During the training and mapping exercises, it was observed that both kinds of categorical icons were often interpreted literally and caused confusion, especially when there was no differentiation between a final leaf icon and an intermediate one.

This may be partially explained by the fact that no visual clues were given to indicate that a depicted item represented a category rather than just its literal self. However, when told certain images represented categories participants expressed a desire for exhaustive descriptions (e.g. adding more fruit examples to the fruit icon), which is problematic in a pictorial interface on a relatively small screen. Interestingly icons that used metaphors rather than examples to describe a category (e.g. a *syringe* to represent '*medicinal flora*'), seemed to work much better (figure 7.10).

User interface improvements

The field deployment exposed many other problems that the users encountered. As a result, after noticing difficulties on either navigating or understanding some elements of the user interfaces, there was an effort to implement new designs *on the spot*. For instance, one of the most challenging UIs for the majority of participants was the interface for choosing whether to make a photo observation or an audio recording, or neither of them by pressing the forward button (figure 7.11a). The specific UI was demanding as it required from the participants to understand and master many abstract concepts in one step – to understand that they could choose either audio or photo, to grasp that this process is not mandatory and finally to move forward by clicking the forward button.

As a possible solution, and while in the field, an attempt to divide the process into two distinct steps, and subsequently into two different interfaces, was made as shown in figure 7.11b and figure 7.11c. On the first step the participants were presented with a screen where they could select if they wanted to attach an audio recording to their observation, by pressing the microphone the recording started and when it stopped the camera interface was shown (figure 7.11b). Similarly, by selecting the microphone with the red cross, they were presented with the camera interface. The same concept was followed for taking pictures, where the participants were implicitly asked by the interface, whether they wanted to take a picture or not (figure 7.11c). This rather simple change had a noticeable impact on participants and on the way they navigated through the application.



(a) Initial UI for selecting between photo, audio or skipping.

(b) Revised UI for selecting between audio and skipping.

(c) Revised UI for selecting between photo and skipping.

Figure 7.11.: Problematic and challenging UIs for participants.

Structured usability trials

Finally, while conducting the structured usability evaluations, it was soon realised that conducting those outside of a controlled environment, imposes a plethora of challenges such as cultural differences, communication difficulties and time constraints. The rest of this section describes these challenges.

First and foremost, the cultural differences introduced a challenge since the communities we were working with were highly cooperative and communal, thus performing individual evaluations was received as strange and awkward. Consequently, bystanders and even translators would often help participants when they struggled to understand or perform the tasks. Stopping people from assisting each other was impossible and was not attempted, as it would be culturally offensive. On the contrary, the collaboration was allowed and the structured usability evaluation was quickly adapted into an observation process of trying to record on notes and on video, for future reference, how the communities interacted with the application.

Communication difficulties and finding good translators was another important challenge to tackle. Most of the research team did not speak or understand the local language and in some cases multiple steps of translation (e.g. English $\rightarrow$ French $\rightarrow$ Lingala $\rightarrow$ Mbendjele and vice versa) were required, with the potential for meaning to be lost, changed or added (figure 7.12).

Next, time constraints were an important issue as the field time in each location was only about 3-4 hours, during which the introduction, training and the actual

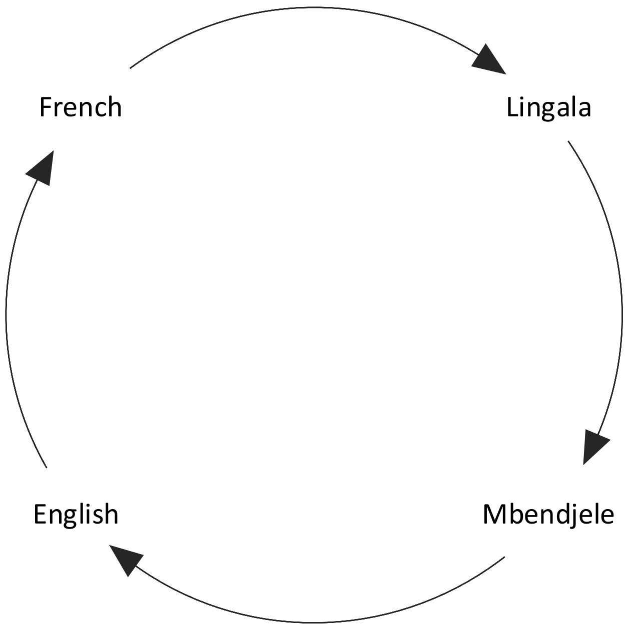


Figure 7.12.: Languages used during training and usability evaluations.

usability tests needed to be conducted. The limited time was due to travelling one the one hand, and due to participants' other obligations (e.g. tending to their fields) on the other. The time frame was very short and strict for both the researchers and the participants, especially considering that this was often the first time participants used a mobile phone.

Finally, an important challenge was the design of the tasks for the evaluation trials. During this first field trip, task scenarios were introduced to participants in the form of short, hypothetical stories. For most participants, these scenarios were abstract and the environment intimidating to properly perform. Thus the results of the trials were less promising than expected and people performed worse than they did during training or the mapping exercises. Research indicates that people who lack formal education, might also lack abilities such as conceptual abstraction (Medhi et al., 2010, 2013). This could be the main reason for participants finding the tasks abstract and hard to perform.

The final outcome of the usability tests was less encouraging than it was expected, in the sense that participants often performed poorly in terms of efficiency as well as accuracy. However, these results can be partially explained by difficulties in communication and the pressure that participants were under due to being evaluated – some of them were performing noticeably better before the actual tests.

7.6 Discussion

The collaboration with Forests Monitor and the local communities, provided ExCiteS with the opportunity to deploy the new ICT platform, as well as gave this research the opportunity to gather in field requirements, observe and interview participants and experiment with conducting usability evaluations. Table F.5 lists the new platform requirements that emerged after the field evaluation, but since the focus of this chapter is on answering the thesis research questions, this section discuss the results of the case study in terms of the two questions. The section starts with the discussion of RQ 2 as it is more general and leads to the discussion on RQ 1.

7.6.1 RQ 2

The second research question of the thesis explored the challenges of designing, evaluating and deploying an ICT system for non-literate participants to capture TEK.

One of the early identified challenges, in the previous case study, was the logistical difficulties in visiting the research area and extracting requirements based on participants' input. This, in combination with other researchers suggesting that users in ICT4D contexts lack the skills to provide feedback and describe their requirements in terms of ICT systems (section 6.2) required for alternative approaches. Hence, in the previous case study, this research employed a proxy to the communities in order to start capturing the challenges and the requirements. In this case study, the limitations of the previous attempt were mitigated by employing more proxies (anthropologists and NGO representatives) and by visiting the research area in person. The original list of requirements was edited, verified and amended taking into account all the new sources. However, comparing the original list of requirements, with the amended list, shows very few differences and demonstrates that although the first approach had many limitations, it proved accurate to a great extend. Therefore, in ICT4D projects, <u>the method of eliciting requirements via a proxy that has extended knowledge of the domain can be used as a low-cost, fast and effective method to gather primary insight and requirements.</u>

Next, this thesis employed cognitive walkthroughs, in both case studies, as a low-cost method to investigate the usability of decision trees before the research field evaluations. This thesis argued that cognitive walkthroughs are very challenging when the participants are so different from the usability experts who conduct the evaluation. To tackle this, field experts that acted as proxies for the end users were also employed. Although, this was a very useful exercise to identify minor usability issues, as the results of this case study demonstrate (section 7.5.2), they fail to identify other interaction challenges such as the navigational issues, abstraction differences etc. Therefore, despite the fact that are easy to deploy and perform, cognitive walkthroughs should be used with caution.

The same applies for conducting usability evaluation through a proxy. This approach could be proved practical as it is a low-cost alternative in cases that the proxy is already in the area, and it can help in the first stages of the research to identify minor usability issues. However, this approach comes with limitations, especially in cases that the proxy is not trained in conducting usability evaluations. As this case study demonstrated, a number of usability issues such as navigational issues and abstraction differences were not identified in the previous case study, but emerged through observational evaluation, the attempted structured usability evaluations and interviews.

Next, this thesis endeavoured to conduct structured usability evaluations '*in the wild*', with the results being less encouraging in terms of conducting the evaluations and in terms of the participants' performance. As noted (section 7.5.2), due to a series of social and cultural challenges, it was impossible to undertake structured evaluations the way that are conducted in controlled environments. Participants were not used to be evaluated in an individual level and therefore participants asked and received assistance from bystanders, translators etc. These results were broadly consistent with other ICT4D evaluations in similar contexts (Chetty and Chetty, 2007; Chetty and Grinter, 2007; Anokwa et al., 2009; Anokwa et al., 2012; Soares and Giesteira, 2015). This, however, was interesting and demonstrated the community's preference to work together, since data collection is not an individual task, but a group task, where people can pass the phone to each other and discuss their results. During those evaluations, it would have been considered culturally offensive to stop people from collaborating and the usability evaluation was quickly adapted into an observation process. However, it was important to establish an individual baseline of performance in order to evaluate decision trees, or alternative interaction methods in the future. As a result, this suggested that an alternative methodology should be sought for conducting evaluations in this context.

Additionally, the use of 'hypothetical scenario tasks' for the evaluation trials, were the tasks were introduced to participants in the form of short, hypothetical stories, proved to be inappropriate. For most participants, these scenarios seemed abstract and participants did not understand what to do. As seen in chapter 4, research indicates that people who lack formal education, might also lack abilities such as conceptual abstraction. This could be the main reason for participants finding the tasks abstract and hard to perform.

7.6.2 RQ 1

The first and primary research question of the thesis, explored the appropriateness of decision trees as an interaction mode for ICT systems for non-literate participants to capture TEK.

In terms of usability, some minor issues such as the participants' tendency to rapidly click on the devices screen which resulted in accidental navigation and the participants hurdle to grasp UIs where the question was optional and they could skip it without answering it were identified. Following a UCD approach and a rapid iteration development cycle, these issues were resolved in the field, by introducing waiting screens and dividing the complicated UIs into different interfaces (section 7.5.2).

However, other essential usability issues were identified. To begin with, the majority of the pictographs were easily recognised, but the interpretation of some icons caused major challenges. While most of them were intended to be interpreted literally (e.g. a banana tree means just that), others were representing categories (e.g. a drawing of a specific game species might represent the concept of hunting, and tapping it would then take the user to a screen offering a choice between multiple icons, each representing a particular game species), which proved to be more challenging. In some cases, these categorical icons occurred as a final choice, but more often they were used at the top or intermediary levels of the decision tree. During the training and mapping exercises it was observed that categorical icons were often interpreted literally and caused confusion.

Although relevant literature suggested no issues, this case study revealed that interface navigation and the understanding of certain icons were hampered by the fact that common symbolic or metaphorical conventions (e.g. arrows [🡐], crosses [✖], ticks [✔], the use of green and red to respectively signify positive and negative connotations) were unknown or interpreted differently. Equally important, many participants seemed to have difficulty understanding the overall hierarchical structure and how to navigate through it using forward or backward steps. As seen in chapter 4, these results are aligned with research undertaken by other researchers e.g. Medhi et al. (2013) in Bangalore, who found that level of formal education is positively correlated with cognitive skills such as conceptual abstraction and categorisation, and thus with the ability to apply these skills when navigating hierarchical interfaces, even when they are text-free. This may also explain the above mentioned difficulties users had when dealing with icons that represent categories, even when occurring as leaves. This suggested that limiting the depth of the hierarchies, possibly even to the point of using flat lists where possible should be considered, but also suggested that more research had to be conducted on the navigational, and structural elements of the UIs to enable participants to better understand the process.

To resolve these issues and improve the recognition of icons, it was obvious that alternative user interactions modes had to be investigated.

7.7 Summary

This chapter discussed the endeavour to enable forest and settled communities in the RoC to participate in monitoring logging activities in their area and capture the socio-economic impact on their lives. In collaboration with the NGOs Forests Monitor and CAGDF, the goal was to pilot a system for collecting evidence on the VPA implementation. For this research, this was an excellent opportunity to evaluate the newly developed *Sapelli* platform in terms of usability, and explore whether decision trees constitute an effective method to capture the data regarding logging.

Over the course of May 2013, in coordination with Forests Monitor, an ExCiteS team visited eight different communities in the northern part of RoC to adapt a decision tree, introduce Sapelli and train participants in using the system. Within that context, this research performed requirements gathering, observational evaluations, structured usability evaluations and interviews to ensure that decision trees are appropriate for the given context.

The results of observing and interviewing participants, and later conducting usability evaluations, were not as encouraging as hoped since some usability and interaction challenges were identified. Some were resolved on the spot, while the most significant, being the difficulty some participants faced when navigating the interfaces due to the abstract structure, needed further research. In addition, the methodology for conducting the evaluations was hampered by a series of cultural and logistical challenges. In the next chapter, we are presenting an endeavour to tackle these challenges by exploring alternative interfaces and interaction modes, as well as an improved methodology for conducting usability trials (chapter 8).

8 Case study 3: Participatory monitoring of logging

> *The truth is: the natural world is changing. And we are totally dependent on that world. It provides our food, water and air. It is the most precious thing we have and we need to defend it.*
>
> — **Sir David Frederick Attenborough**
> (English broadcaster and naturalist)

This chapter[1] introduces the collaboration with the logging company CIB, to deliver an ICT system that would enable local forest and agricultural communities to map their local resources and protect them during the upcoming logging sessions. This would enable CIB to improve the efficiency and accuracy of their paper-based resources mapping on the one hand, and enable local communities to be directly involved on the other.

The previous field evaluation, as discussed in chapter 7, led to the discovery of a number of interaction challenges that had to be tackled. In terms of this research, this case study endeavours to evaluate the usability of decision trees, complimented with audio feedback, and physical interfaces in this context, and therefore answer the two research questions, as defined in chapter 4.

In the following sections, this chapter introduces the social context of the case study (section 8.1), and then turns on the list of functional requirements for the ICT platform (section 8.2). Section 8.3 briefly describes the development of alternative user interaction modes, and then section 8.4 presents the evaluation of these modes, in field, by the communities. Finally, section 8.5 discusses the results of the evaluation and the methods employed.

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[1]Parts of this chapter are published in:

a) Vitos, Michalis, Julia Altenbuchner, Matthias Stevens, Gillian Conquest, Jerome Lewis and Muki Haklay (2017). "Supporting Collaboration with Non-Literate Forest Communities in the Congo-Basin". In: *Proceedings of the 20th ACM Computer-Supported Cooperative Work and Social Computing*. ACM CSCW '17. Portland, Oregon, USA: ACM. forthcoming.

8.1 Social context

This case study is situated in the same social and geographical context as the previous case study, discussed in chapter 7. As noted in section 7.1, the Congo Basin hosts a number of settled and forest communities that rely on the rainforest for a series of ecosystem services. However, the current political situation divides the rainforest into PFEs and NPFEs, with the permanent areas to be usually subdivided in logging and mining concessions. In addition, as local governments have not the capacity to develop infrastructures in remote areas of the rainforest, they include a series of social responsibility agreements ('*cahier des charges*') as part of their contract with logging companies, which results in private logging companies influencing significantly the standard of living of local communities.

However, the legal context is improving since 2010 when Republic of the Congo signed a VPA with EU that includes a series of principles regarding the active involvement of local communities in the management of the forest concession (see section 7.1). Moreover, sustainable responsible companies such as CIB have already sought to acquire an FSC accreditation. FSC is an international, non-profit NGO that promotes sustainable management of forestry resources and requires logging companies to respect the rights and resources of indigenous and local forest communities (FSC, 2015).

As evident from the collaborations with NGOs and industry actors noted in the previous chapters, partnerships with intermediary actors play an important role if participatory monitoring projects are to be funded and managed sustainably. It is therefore often necessary to begin by establishing relationships with intermediaries who have a sustained local presence, sufficient expertise in local conditions, and who are trusted by local communities. Such partnerships work to lend legitimacy to a project from the point of view of participants and other local stakeholders.

Within this context, ExCiteS collaborated with CIB, in 2015, to provide them with a Sapelli-based solution that would enable communities to participate again in mapping their resources. By directly involving Mbendjele community members, the logging company's social team hoped to improve local understanding of the mapping process by introducing the ability for Mbendjele community members to be directly involved.

In the context of this individual research, the logging company CIB were the key intermediary in the area and they offered their assistance in multiple levels. First of all, they offered direct access to the company's social team which was responsible for organising mapping sessions with the local communities. The social team's contribution was crucial to this research, since they introduced the author to local communities, acted as facilitators, research assistants and translators. CIB also arranged logistical issues such as transportation from Brazzaville to their logging concession and vice versa and the transportation to and from local communities by proving the research team with a 4x4 car and a driver. Within the context of our collaboration, the goal for ExCiteS was to transfer the technology and methodologies to the social team, so that they could continue to apply the same approach after the field evaluations. In terms of this research, this collaboration was a significant opportunity to investigate (a) alternative interaction modes such as audio feedback, physical interfaces etc., (b) alternative methods for conducting usability evaluations within that challenging context.

8.2 Requirements analysis

As in the previous case study (chapter 7), the list of requirements was amended and extended following the field evaluation (section 7.5.2).

In 2013, ExCiteS collaborated with the international NGO Forest Peoples Programme (FPP)[2] and their vision was to use the Sapelli platform for community mapping in combination with textual data capture. This would be useful in cases where users with different abilities or roles needed to access the same device. For instance, NGO representatives could set up monitoring sessions using a textual form, after which the same device could be passed on to non-literate community members to collect data associated with that session. Hence, after the field evaluation, this discussion with other NGOs for potential collaborations and Sapelli deployments, in combination with the internal discussions of the ExCiteS team led to a revised list of requirements (see table I.1 in appendix I).

In terms of this research, the most important requirements, that had to be met, were the need for alternative interaction modes within the Sapelli platform, to alleviate the usability issues, as identified in the previous case study (section 7.5.2). The next section discuss the development of these alternative methods.

8.3 Prototype development

The *Sapelli* platform undertook a list of improvements and changes in light of the new requirements. These changes are described in appendix I.2, but are out of the scope of this chapter to further discuss. This chapter focuses on the interaction

[2]http://www.forestpeoples.org

challenges, as revealed in section 7.5.2. During the previous field evaluation, both minor and major usability issues were identified. The former were resolved while in the field with modifications to the UI, but the latter required more research to enable participants to better use the platform.

To begin with, the majority of the pictographs were easily recognised, but the interpretation of some icons caused major challenges. While most of them were intended to be interpreted literally (e.g. a banana tree means just that), others were representing categories (e.g. a drawing of a specific game species might represent the concept of hunting, and tapping it would then take the user to a screen offering a choice between multiple icons, each representing a particular game species), which proved to be more challenging. In some cases, these categorical icons occurred as a final choice, but more often they were used at the top or intermediary levels of the decision tree. During the training and mapping exercises it was observed that categorical icons were often interpreted literally and caused confusion.

In addition, interface navigation and the understanding of certain icons were hampered by the fact that common symbolic or metaphorical conventions (e.g. arrows [🡸], crosses [✖], ticks [✔], the use of green and red to respectively signify positive and negative connotations) were unknown or interpreted differently. Equally important, many participants seemed to have difficulty understanding the overall hierarchical structure and how to navigate through it using forward or backward steps.

Finally, although that the icons were co-designed with the communities, not every participant was present in the initial phase of designing or choosing the icons. However, it was important for participants to be able to identify the meaning of an icon, or grasp the questions that are being posed at given screens, even after long periods of not using the system or when they navigate through parts of the decision tree that they were never trained on or they had only briefly used in the past.

To resolve these issues and improve the recognition[3] of icons, two potential solutions were explored, UIs with audio feedback and physical interfaces. The rest of this section describes the audio feedback mechanism that was introduced to explore a solution for requirement, and explains the introduction of a logging mechanism in the core of the Sapelli platform to study participants' navigational patterns.

[3]Recognition refers to the ability to identify some piece of information as familiar, while recall refers to the ability and process of retrieving detailed information from memory (Budiu, 2014). As explained in section 4.2, recognition is preferred over recall, when designing UIs, in an effort to minimize the user's memory load. As a result, recognition was selected as a usability measure for this thesis.

8.3.1 Audio Feedback

As seen in section 4.4, providing information across different human senses can have a positive impact on a participant's performance and audio has been employed in various projects within the ICT4D context. Since audio has shown promising results in other ICT4D scenarios, it was decided to augment the decision trees with audio cues that would reduce the cognitive load on participants and potentially increase their abstract problem solving.

In Sapelli projects, a pictorial decision tree represented a question posed to the user, with a list of available options (i.e. icons) to choose from. Hence, the prototype was implemented so that upon reaching a new screen (i.e. decision tree root or node), an audio file narrated the question and then each icon on the screen were sequentially explained by audio playbacks, while an animation signalled which icon was described. In addition, participants could long-click on any item, such as an icon or a navigation element, to listen again to a playback describing the particular item.

In addition, the prototype was designed to offer two types of audio feedback upon reaching a new screen:

1. The first was to record audio clips for each of the UI elements and associate them with the correct element within the XML definition of the project, as presented later on. This of course requires a lot of preparation as a large number of audio clips has to be recorded and it is not flexible for quick iterations. The number of audio clips to be recorded equals the number of pictorial icons, plus the navigational elements and plus audio clips that describe the question that is imposed when entering a screen.

2. The second employed the Android text-to-speech (TTS) service to produce audio files from a textual description on-the-fly. In this way, no pre-recording was required, but rather a text description of each icon, which was written on the project's XML. For widely spoken languages, Android offers the TTS, however, for less common languages, such as Lingala[4] or the hundreds of local Bantu and Ubangian derived languages such as Mbendjele, speech synthesis is not supported and might never be supported. Although TTS was not supported for those, it was envisioned that it could be practical: (a) in other contexts where TTS is supported – such as the Amazon where Portuguese is commonly spoken and an ExCiteS researcher was already using Sapelli; (b) in

[4] a Bantu language commonly spread throughout the north-western part of the DRC and the Republic of the Congo.

the process of designing and testing a project where TTS would allow quick iterations compared to recording actual audio clips. For instance, in the RoC, the main spoken language is French, and having TTS to quickly demonstrate the functionality to NGOs, or other stakeholders, was a valuable asset.

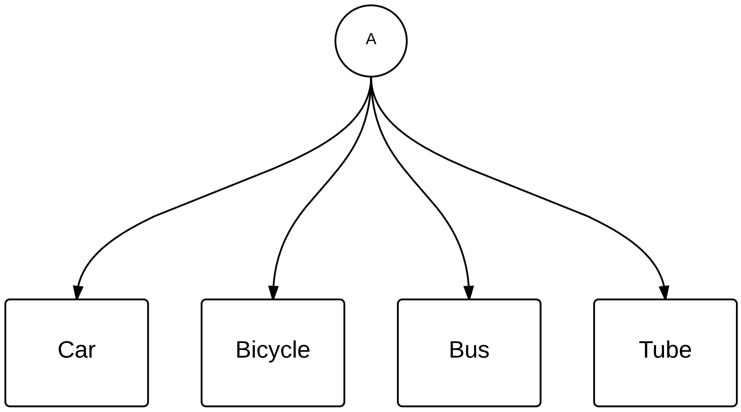


Figure 8.1.: Decision tree for audio feedback example.

For project designers, audio feedback was designed to be activated in two simple steps on the XML level:

Step 1: Define the language for TTS (if TTS is required);

Step 2: Add questions and answers for the choices either as text (if TTS is used), or audio files, or both.

To demonstrate this, a very simple decision tree on transportation mode preferences will be used as an example. The tree asks users whether they prefer to travel by *Car*, *Bicycle*, *Bus* or *Tube* (figure 8.1). Once the user responds to the answer, the application registers the user's GPS position and displays the user with a confirmation screen to accept or discard the observation. Figure 8.2 shows how the UI will be presented on the *Sapelli Collector*, while listing 8.1 illustrates the XML code required to describe the example.

As the XML code shows, the following two steps define and control the various aspects of the audio feedback:

Step 1. The attribute `defaultLanguage`, in `<SapelliCollectorProject>` tag, defines the language to be used for TTS in BCP-47[5] syntax. In this example '*en-GB*' defines

[5] A BCP-47 tag is an abbreviated language tag defined by Internet Engineering Task Force (IETF) to describe the language of HTML and XML files. For instance, '*en*' stands for English, while '*en-US*' stands for American English.

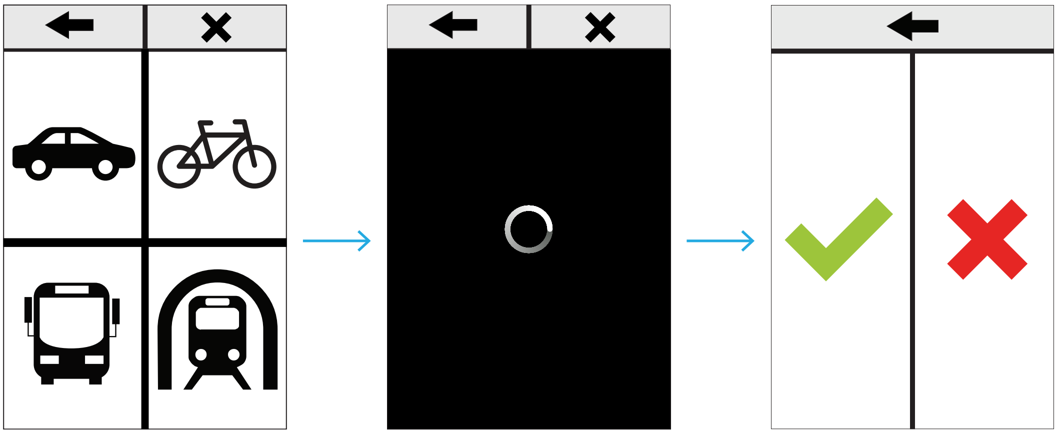


Figure 8.2.: UI for audio feedback example. *Icons © Flat Icon*

that *British English* will be used to synthesise audio from text, whenever an audio file is not provided.

Step 2. Finally, the questions and answers are defined by using the attributes `questionDescription` and `questionAnswer`, in the `<Choice>` tags, respectively. This example uses a mixture of TTS and pre-recorded audio files. For instance, when the user opens the form, TTS will be used and play back to the user the following message '*Please select one of the following modes*'. Since the audio feedback mode is set to *sequential*, then all four options will be played back. For the first two (*Car* and *Bicycle*) TTS will be used. While for the last two (*Bus* and *Tube*) an '*mp3*' recording is provided. Similarly, when the user enters the confirmation screen, he will be presented with the following audio clip, '*Please confirm or cancel your selection*', and then '*Confirm*' and '*Cancel*'.

Listing 8.1: XML example of audio feedback

```
<?xml version="1.0" encoding="UTF-8"?>
<SapelliCollectorProject id="1234" name="Transport Audio" version="1.1"
    defaultLanguage="en-GB" >

  <Form id="TransportSurvey" audioFeedback="sequential" >

    <Choice id="TransportMode" questionDescription="Please select one of the
        following modes">
      <Choice img="car.svg" value="Car" questionAnswer="Car" />
      <Choice img="bicycle.svg" value="Bicycle" questionAnswer="Bicycle" />
      <Choice img="bus.svg" value="Bus" questionAnswer="Bus.mp3" />
      <Choice img="tube.svg" value="Tube" questionAnswer="Tube.mp3" />
    </Choice>

    <Location id="Position" type="GPS" timeout="120"/>

    <Choice id="Confirmation" noColumn="true" questionDescription="Please confirm or
        cancel your selection">
```

```
      <Choice img="ok.svg" jump="_LOOPFORM" questionAnswer="Confirm" />
      <Choice img="cancel.svg" jump="_CANCEL" questionAnswer="Cancel" />
    </Choice>

  </Form>

</SapelliCollectorProject>
```

8.3.2 Log user interactions

Log analysis was used in the first prototype and it revealed some first indications of navigational issues in regards to categories (see section 6.5).

Hence, in order to better understand the user interactions and study the participants' navigation patterns through the application, logging functionality that records every single interaction happening on the system has been implemented. The logger produced a comma-separated values (CSV) file with all the decision tree's icons that the user pressed and the exact moment by also saving a timestamp value. The logger also recorded information such as when a project and a form was opened and when a record was saved to the database etc. Using such a tool could assist to better understand the navigation pattern users followed and how much time they spent on specific user interfaces. For instance, listing 8.2 shows the logs of an observation captured for the transportation mode example presented in appendix F (see figure F.5). From the output, it is worth mentioning that the participant required 31 seconds (line 23) to report that he prefers '*Walking*' as his transport mode (line 14).

Listing 8.2: Sapelli log interactions

```
1  2016-07-02T18:01:39.900+01:00;Device ID (CRC32);4155932026
2
3  2016-07-02T18:01:39.900+01:00;PROJECT_START;Transport Demo (v2.3)
4
5  2016-07-02T18:01:39.902+01:00;FORM_START;Survey (index: 0);mode: CREATE
6  2016-07-02T18:01:39.914+01:00;REACHED;TransportMode
7  2016-07-02T18:01:39.914+01:00;CHOICE_OPTIONS;[ChoiceField TransportMode.1,
       ChoiceField TransportMode.2]
8  2016-07-02T18:01:43.489+01:00;CLICKED;ChoiceField TransportMode.1 (img: private.svg
       )
9  2016-07-02T18:01:43.490+01:00;REACHED;TransportMode.1
10 2016-07-02T18:01:43.490+01:00;CHOICE_OPTIONS;[ChoiceField TransportMode.1.1,
       ChoiceField TransportMode.1.2]
11 2016-07-02T18:01:45.190+01:00;CLICKED;ChoiceField TransportMode.1.2 (img:
       unmotorised.svg)
12 2016-07-02T18:01:45.191+01:00;REACHED;TransportMode.1.2
```

```
2016-07-02T18:01:45.191+01:00;CHOICE_OPTIONS;[ChoiceField TransportMode.1.2.Bicycle,
     ChoiceField TransportMode.1.2.Skateboard, ChoiceField TransportMode.1.2.
    Walking]
2016-07-02T18:01:47.497+01:00;CLICKED;ChoiceField TransportMode.1.2.Walking (value:
     Walking; img: walking.svg)
2016-07-02T18:01:47.498+01:00;REACHED;Position
2016-07-02T18:02:06.119+01:00;REACHED;Confirmation
2016-07-02T18:02:06.120+01:00;CHOICE_OPTIONS;[ChoiceField Confirmation.1,
    ChoiceField Confirmation.2]
2016-07-02T18:02:08.481+01:00;CLICKED;ChoiceField Confirmation.1 (img: ok.svg;
    caption: Confirm)
2016-07-02T18:02:08.482+01:00;REACHED;Confirmation.1
2016-07-02T18:02:08.482+01:00;CHOICE_OPTIONS;[ChoiceField Confirmation.1.1,
    ChoiceField Confirmation.1.2]
2016-07-02T18:02:10.338+01:00;CLICKED;ChoiceField Confirmation.1.1 (img: restart.
    svg; caption: Another)
2016-07-02T18:02:10.338+01:00;REACHED;_SAVE+LOOPFORM
2016-07-02T18:02:10.338+01:00;FORM_END;_SAVE+LOOPFORM;Survey;31 seconds
2016-07-02T18:02:10.347+01:00;RECORD;Record<Schema{Transport_Demo_(v2.3):Survey}>:[
    StartTime = 2016-07-02T18:01:39.901+01:00; StartTime-LocalYYYYMMDD_HHMMSS =
    '2016-07-02 18:01:39'; StartTime-UCTOffsetH = 1.0; StartTime-UnixMS =
    1467478899901; DeviceID = 4155932026; TransportMode = 5; TransportMode-Value =
    'Walking'; TransportMode-Image = 'walking.svg'; TransportMode-Caption = null;
    Picture = null; Picture-Files = null; Position = 51.53860833333333,
    -0.12201333333333333, 53.0, 0.0, 0.0, 16.299999237060547, 2016-07-02T18
    :02:06.000+01:00, 1; LosslessFlag = true]
```

8.4 Evaluation

In order to evaluate the feasibility of the approach and the newly designed features, a field evaluation was organised in early 2015, in collaboration with CIB. Although that cognitive walkthroughs are easy to deploy and cost-effective, the previous case study demonstrated that they should be used with caution as they do not reveal major usability issues in this context (see section 7.6). As a result cognitive walkthroughs were not used, but just field evaluation was arranged instead.

While in field, the logging company's social mapping team, who is composed of Mbendjele staff, was the local intermediary with the communities. Apart from introducing the author to local communities, they also acted as research assistants and translators, and their contribution was extremely valuable.

Decision tree The goal of the project, from CIB's perspective, was to enable communities to map their resources, while the goal for this research was to explore the applicability of decision trees with audio feedback and physical interfaces for the same purpose. As the previous case study revealed a navigational issue with decision trees, it was decided that this decision tree should be simpler in terms of depth and available options, to further investigate the limitations of decision trees.

Thus after a discussions with the social team of CIB, it was decided to use a reduced version of the decision tree that was previously designed during our collaboration with Forests Monitor and CAGDF (see chapter 7). In the context of this field trip, only part of that decision tree related to resources mapping was used and it was further modified after discussions with the social cartography team. Their modifications related mostly to the structure of the tree, adding and eliminating some categories and making alterations to specific icons which they argued would make the icons more comprehensible for the communities. The final decision tree is presented in figure 8.4, and it was composed of two levels and a total of 26 icons. On the first level, participants were able to choose amongst 6 pictographs (categories) that represented: (a) agricultural resources; (b) cultural and religious sites; (c) sacred sites; (d) gathered resources; (e) fishing resources and (f) hunting sites. The second level gave the participants more specific options for each of the first level choices, while *hunting sites* had no second level options.

Table 8.1.: Communities visited in field evaluation ordered by date of visit.

Community	Ethnic groups	Visit length
Gbagbali	Pygmy (Mbendjele)	1 day
Kabo	Pygmy (Mbendjele)	1 day
Gbagbali	Pygmy (Mbendjele)	1 day
Matoto	Pygmy (Mbendjele & Mikaya)	1 day
Matoto	Pygmy (Mbendjele & Mikaya)	1 day
Sembola	Pygmy (Mbendjele)	2 days

Note. [1]Anthropology [2]Computer Science [3]GIS
Researchers are listed in alphabetical order based on the surname.

Communities Next, the social teams facilitation allowed visits to 4 different communities to be arranged in a period of 3 weeks and conduct usability evaluations of the platform to resolve some of the usability challenges that we identified in our previous chapter. Table 8.1 lists the visited communities, while figure 8.3 shows the research area.

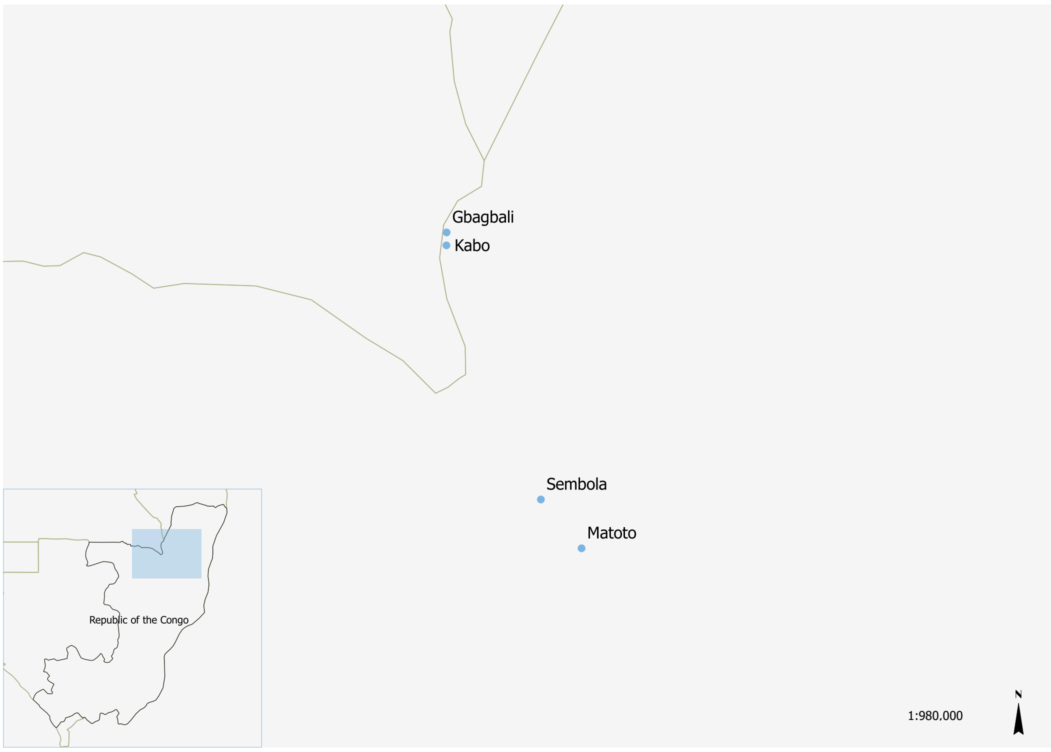


Figure 8.3.: Case studies map.

As also mentioned in the previous case studies, local communities speak either the locally spread Lingala, or their local Bantu or tribe language. In order to conduct the usability evaluations, translators were employed. Members of CIB's social team acted as translators from the local tribe languages to French, while another translator was employed for French to English. Once again multiple steps of translation were required (e.g. English → French → Lingala → Mbendjele and vice versa, as seen in figure 7.12 on page 140), with the potential for meaning to be lost, changed or added.

Methodology As in the previous case study, the evaluation conducted for this research, was part of a wider ExCiteS field trip. In each of the communities, the FPIC approach was applied to introduce and train participants (Lewis and Nkuintchua, 2012; Stevens et al., 2014). As before, for this research participants observation was applied during the introduction and training sessions (steps 2-4) (figure 8.5). Figure 8.6 illustrates parts of steps 1-4. After step 4 was completed, a structured usability evaluation and semi-structured interviews were then conducted, in each of the communities, as described in the next sections.

In the rest of the section the evaluation of interfaces complemented with audio feedback (section 8.4.1) and the physical interfaces will be presented (section 8.4.2).

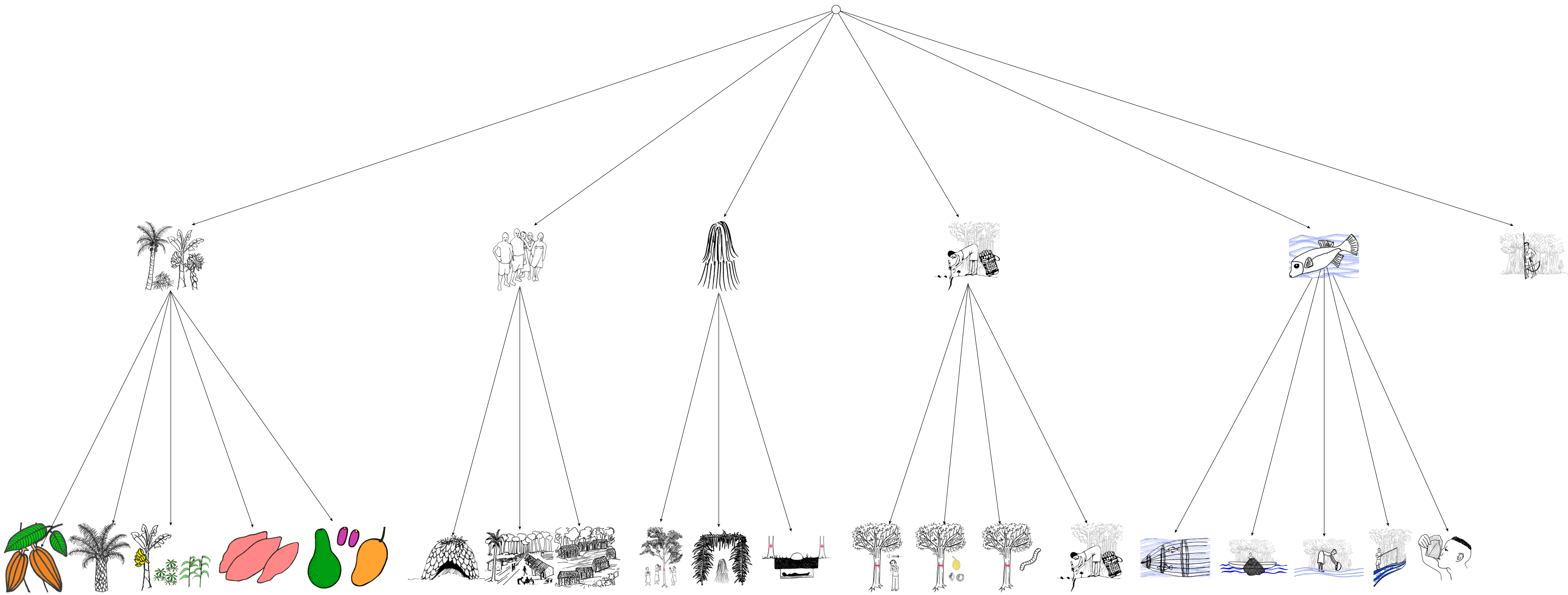


Figure 8.4.: Decision tree designed in collaboration with CIB.

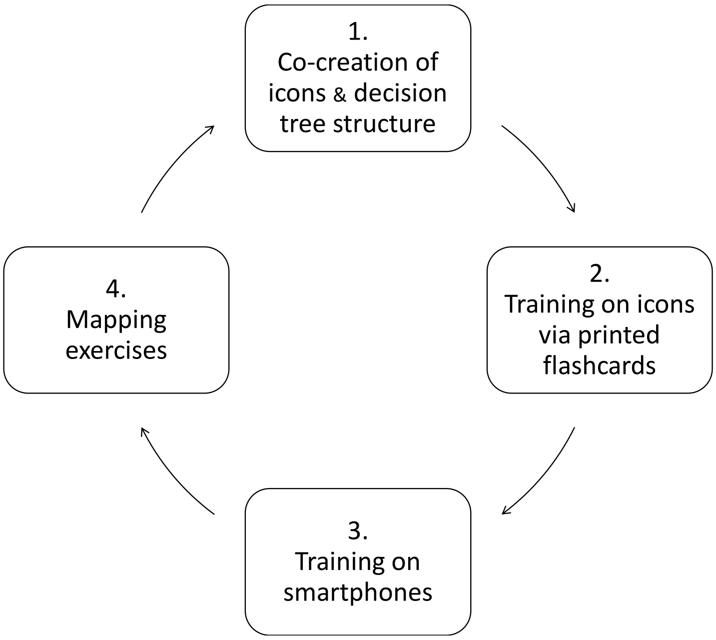


Figure 8.5.: Training and introduction steps.

(a) Training via flashcards

(b) Training session

Figure 8.6.: Training sessions conducted by research assistants. © *Michalis Vitos, ExCiteS group*

8.4.1 Audio feedback

The audio feedback feature was evaluated against 4 different communities (Gbagbali, Kabo, Matoto and Sembola) in northern RoC. The visited settlements were selected after a consultation with the social mapping team of CIB, and were either close to CIB's facilities or deep in the forest, reachable only by 4x4 journeys over narrow dirt roads or the occasional boat ride.

A total number of 48 adult participants (24 males, 24 females) took part in the evaluations and were selected on a voluntary basis on the day of the evaluations. Aged between 18 and 69 years old (M=34.5, SD=12.5), the majority of the participants were Mbendjele (98%), while 2% were Bangombe. A 50% of the participants had received no formal education, 38% had primary school education, 6% had secondary education, while another 6% stated they had received some education but could not specify which level they had reached.

As described above, the decision tree we used for the trials was a reduced version of the one previously designed for the collaboration with Forests Monitor and CAGDF. When the decision tree was finalised and no more edits were required, one member of CIB's social team was recorded in the local Mbendjele language, narrating all the questions and icon descriptions to be used in the audio feedback version. Figure 8.7 shows parts of the decision tree as it was presented on the Sapelli Collector app. Next, the Sapelli survey was loaded on eight *Samsung Xcover 2*[6] smartphones.

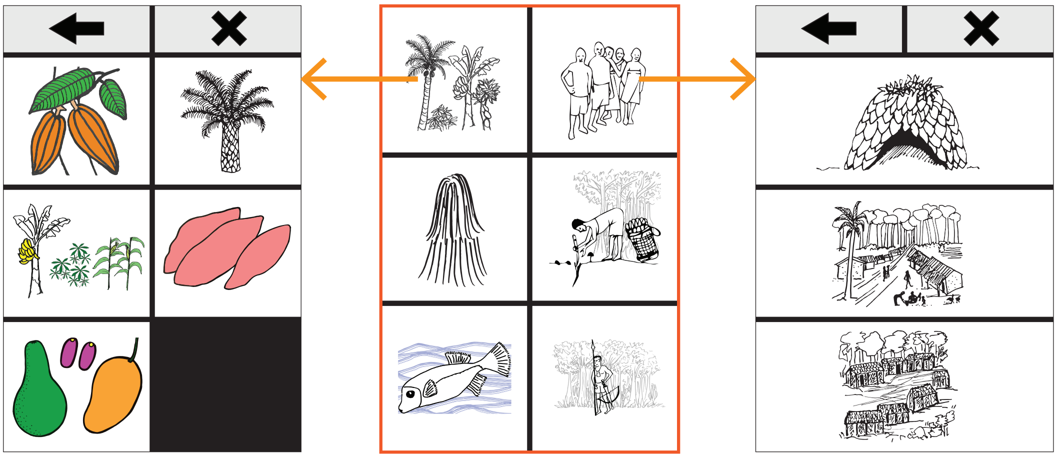


Figure 8.7.: Part of decision tree used for CIB trials.

The goal of the evaluations was to evaluate participants' accuracy and recognition by providing them with a set of representative scenario tasks to complete using both versions, with and without audio feedback. In the first two communities, Gbagbali and Kabo, participants first performed the tasks without audio feedback and then completed the same tasks with audio feedback. To counterbalance the results, the reverse order was followed in the last two communities, Matoto and Sembola, where participants used the version with audio feedback to perform their tasks, and later they did the same with audio feedback switched off.

The experience of conducting the previous usability evaluations in the wild (see chapter 7) revealed that tasks based on hypothetical scenarios (e.g. '*Suppose you are...*') do not work well with participants. Thus, it was decided to ask the participants to perform five practical tasks, where they had to collect data for five nearby resources under different top-level categories of the decision tree. All the selected points were valuable resources for the community that they would like to protect against damage from future logging activities. For instance: medicinal

[6]http://www.samsung.com/uk/consumer/mobile-devices/smartphones/others/GT-S7710TAABTU (Accessed on 7th Feb. 2016)

trees, the local cemetery, cacao trees etc. In addition, to avoid bystanders helping participants who were struggling to understand or perform the tasks, the five points of interest were deliberately chosen to be away from the village but within a short walking distance. Walking from the first point to the last, would take about 15-20 minutes, depending on the village and its proximity to the resources. Before the evaluations, one of the research assistants / translator, along with one or two community members and the author walked in the nearby area to identify the resources to be used for the evaluations. With the community members' active assistance, five appropriate points for the evaluations were located.

On the day of the evaluations, the FPIC process, described in the previous section, was followed to introduce the project, the project scope, and the Sapelli software. Once people seemed comfortable with the application and the way of 'tapping' the icons and moving between screens, they were asked to participate, in pairs, in the task trials. Based on the previous usability evaluations (chapter 7), it was revealed that people preferred to work together, since data collection was not an individual task, but a group task, where people could pass the phone to each other and discuss their results. Participants were accompanied during each task by the author and two research assistants, who were facilitating the translation, note-taking and video-recording of the participants' interactions with the devices. At each of the sites, the participants were asked to describe the point of interest in front of them (e.g. a medicinal tree), to ensure that they understood its significance. The participants were each holding a smartphone with Sapelli loaded and were then asked to record the type and location of the point. Their task was to follow the appropriate path of the decision tree until they reached the corresponding leaf icon, followed by a screen where they could confirm the observation. At that point, their response was coded as correct or incorrect, while the Sapelli app was also logging all the interactions with the device (see section 8.3). Conducting an Action Analysis (also known as Keystroke-Level Analysis, see page 79) before the evaluations, it was concluded that all tests needed around a minute to be performed, with the actual figure depending on the time needed for a GPS fix which varied depending on the location. However, the action analysis time could only be realised by an experienced user, who made no mistakes while completing the tasks. To leave room for mistakes, indecisiveness and to not stress participants, it was decided that each participant would have a maximum time of 5 minutes to complete a task, although in the evaluations no participants needed more than two minutes to record an observation.

Initially participants were asked to 'think aloud' and describe to each other what they felt regarding the process and describe their actions, but it was soon clear that they were either too nervous, or lacked the vocabulary and contextual understanding, to describe their actions. For example, some participants produced responses such as '*I am using this [Sapelli app or device] to protect the forest*', which were not particularly useful in terms of evaluating the usability of the platform and thus the think aloud technique was abandoned.

Following completion of the tasks, interviews with the two participants, comprising both structured and semi-structured questions, took place. The interviews were video-recorded for later reference and transcription. During the interviews, it was endeavoured to facilitate a discussion on usability of and user satisfaction with the app, and to identify the reasons for some participants' poor performance on certain tasks. Finally, participants were compensated with XAF 2,000 (approximately £2.8) for taking part in the evaluations.

Audio feedback results

As shown in table 8.2, the 48 participants completed 240 tasks without, and 240 tasks with, audio feedback enabled. When using the version without audio assistance they performed 177 successful observations (73.75%), while using the version with audio assistance, they performed 185 successful observations (77.08%). The audio prompt thus seemed to be effective in slightly improving participant accuracy. However, performing a *paired t-test* revealed that the mean increase in accuracy (M=0.16, SD=1.15) was not statistically significant (t(47)=1, p=0.32). Figure 8.8 shows the accuracy for both versions on relation to the number of correct tasks.

Table 8.2.: Audio feedback results

Success	Non-Audio	177 **(73.75%)**
	Audio	185 **(77.08%)**
Failure	Non-Audio	63 **(26.25%)**
	Audio	55 **(22.92%)**
Number of Tasks	Non-Audio	240
	Audio	240

As noted, Sapelli recorded each single interaction happening on the system (see section 8.3). Analysing the logs of the trials showed that participants required an average of *26.5* seconds (median 23 seconds) to perform a single observation without audio feedback (figure 8.9). Similarly, participants required an average of *28.4* seconds (median 19 seconds) to perform a single observation using audio feedback.

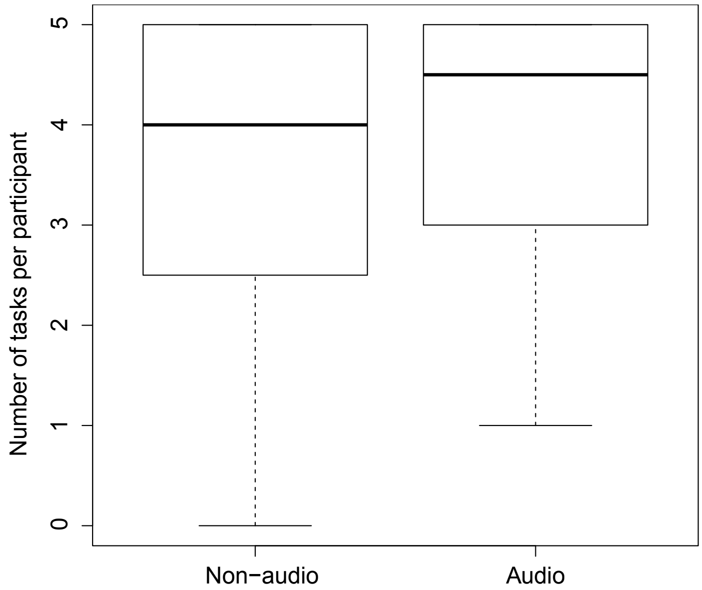


Figure 8.8.: Accuracy performance for non-audio and audio tasks.

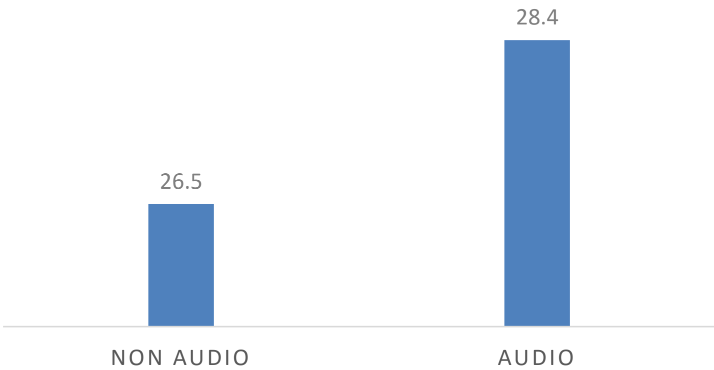


Figure 8.9.: Completion time (in seconds) for non-audio and audio tasks.

Further analysis on the logs was conducted and the preference of the various UI components was calculated. Figure 8.10 shows the popularity of the elements shown on a Sapelli screen such as icons, navigation buttons (back and cancel) and the long-click interaction. For instance, when participants used the non-audio version to complete 240 tasks, 87.94% of their clicks were pictorial icons, 8.53% and 3.43% were the back and the cancel buttons respectively and 0.10% of their interactions was a long-click. Respectively, for audio 95.90% of participants' clicks were pictorial icons, 1.54% and 2.66% were the back and the cancel buttons, while there was no long-click recorded. Both audio and non-audio results suggest a strong participants' preference on pictorial icons and hesitance to use the navigational icons (back and cancel), or the long-click feature that would trigger an audio playback.

Although there was no statistical difference in using one of the versions in terms of accuracy, there was a significant difference in terms of user experience and user

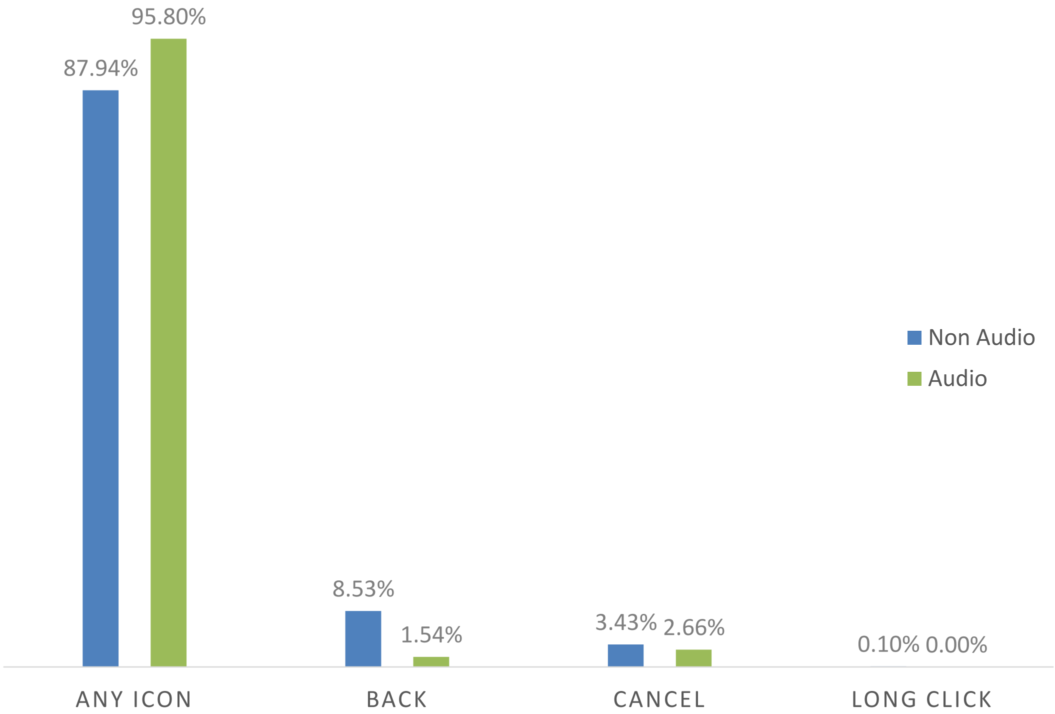


Figure 8.10.: Clicks per item for non-audio and audio tasks.

satisfaction. During the interviews, 33 out of the 48 participants (69%) stated that they preferred the version with the audio feedback. The main reason given was that the device was speaking their local language, which they found entertaining and reassuring. For many participants the version with audio prompts had a pedagogic element, as it reminded them of school and provided them with knowledge about the icons and the project. For others, the audio feedback was a good way of verifying what they already knew, and of giving them reassurance that they were selecting the appropriate icons. One interesting case involved an older woman who stated that she liked the audio version because her bad eyesight did not allow her to clearly distinguish the icons. Finally, one participant stated that she loved hearing the question, as this made choosing the right icon easier for her. Thirteen participants (27%) stated that they liked both versions and could not decide on one; according to them both were very practical and easy to use. Finally, only two participants preferred the version without audio, the first participant was comfortable enough without audio and stated that he didn't need it, while the second claimed that the audio prompt was very distracting for him, since he already knew the answers.

Interestingly, the results indicate that the success rates of decision trees are correlated with the literacy level of the participants and their exposure to technology (table 8.3). In Gbagbali and Kabo, two remote communities with lower literacy levels, the success rate for decision trees, without audio, was 63.3%. When asked if they had ever used a mobile phone before (feature phone or smartphone), only 8% of participants replied positively. In Matoto and Sembola, communities with higher education levels, which are located closer to the logging company's camp and which have easier access to technology (33% of participants claimed that they had used a phone before), the success rate was 84.1%.

Table 8.3.: Decision tree results in relation to education and technology familiarity.

	Gbagbali, Kabo	Matoto, Sembola
Education level		
No formal education	50%	50%
Primary school	42%	33%
Secondary school	0%	13%
Unknown[1]	8%	4%
Technology familiarity		
Used mobile phone before	8%	33%
Success rate		
Non-audio	63.33%	84.17%
Audio	66.67%	87.50%

Note. [1]*Unknown* represents participants who stated that they had received some education but could not specify which level they had reached.

8.4.2 Tap&Map: Exploring physical interfaces

While in the field, the initial analysis of the audio evaluations revealed that even though pictorial interfaces reduce the accessibility barriers that text introduces, still they do not provide a universal solution. This was because many participants, especially those who have never had any formal education or who were completely unfamiliar with digital technology, faced difficulties using the application that audio prompts could not assist with. The main barriers identified after close observation and follow-up interviews during the audio feedback trials were: (a) fear of using technology; (b) difficulties in navigation; and (c) inappropriate categorisation.

Many participants, especially those less familiar with technology, expressed a fear or hesitancy around using the smartphones and their touch-screens. In addition, their lack of experience regarding how to tap the display, in combination with fingertip callouses formed as a result of manual labour, restrained participants from easily using the touch-screen and exploring the affordances of the application. The unresponsiveness of the screen led to frustration in some cases, as tapping an icon did not produce any results.

Although the participants did understand the significance of each icon, the interviews showed that some had difficulties with the hierarchical navigation structure and the categorisation implicit in a decision tree. The problem seemed to be twofold: on the one hand participants seemed to not understand the abstract hierarchical structure and the icons used for navigational purposes at the top of the screen. For instance, the function of the icons for navigating back to the previous interface (left arrow [🡐]), and for cancelling an observation (cross [✖]) (figure 8.7, left & right UIs) were not clear to all participants and they were rarely used. That was also confirmed by the analysis on the Sapelli logs (figure 8.10). When asked, one Mbendjele woman said that the left arrow represents medicinal resources, while a Mbendjele man believed it represented '*a path leading to the cemetery*'. The same woman believed that the cancellation cross represented cacao trees, while the man could not explain the significance of the cross. Although these icons were grouped together at the top of the screen and had different look and feel than the 'normal' Sapelli icons (different size & background colour), it was clear that participants did not understand their navigational role and misinterpreted them as ordinary icons that should be used for mapping resources.

In addition, the categories themselves and the icons designed to represent them were difficult to interpret. During the recording of the audio clips for the audio feedback evaluations it became evident that no generic terms existed in the local language for some of the categories. To compensate for that, the audio recordings were often very descriptive and verbose, trying to give examples for the category. On top of that, designing icons for the categories was a major challenge. As explained in chapter 7, some of the decision tree icons were intended to be interpreted literally while others were meant to represent (intermediate) categories. Yet during the field trials it became clear that category examples were often interpreted literally.

For these reasons, it was decided to abandon further evaluations of the audio feature, and instead use the remaining time in the field to explore an alternative interface with a focus on eliminating categorisation and navigational structures and reducing the need for interaction with the device. As seen in section 4.4, at that moment there was a growing interest in forms of interaction that combine physical objects and graphical interfaces. TUI could offer increased affordances and embodied cognition that could alleviate the categorisation and navigational issues that were revealed.

For that reason, a system consisting of two elements was conceptualised to investigate physical interfaces: (a) a series of cards, each with an icon representing a point of interest to be mapped; and (b) a smartphone application. Each card would be equipped with a NFC tag and would then act as a tangible user interface. The application would react when one of the 'control' cards is touched on the device. When, for example, a participant wanted to record a point of interest, such as a medicinal tree, he or she could: (a) select the appropriate card from a stack of cards i.e. the medicinal card (figure 8.11b); (b) touch the card to the phone while standing as close as possible to the site to be mapped (figure 8.11c). That simple pairing would trigger then the device to read the user's location from the GPS sensor and store it along with other necessary metadata (such as the selected card, device id, time, etc.).

This concept was called *Tap&Map*[7] and it was hypothesised that in comparison to on-screen decision trees it could enable a simpler and more intuitive approach for non-literate participants to map local resources (or collect other kinds of information depending on the project scope).

(a) Printed prototype cards. **(b)** Picking the appropriate card. **(c)** Mapping a medicinal tree.

Figure 8.11.: Prototype version of Tap&Map.

Tap&Map evaluation

Following a rapid prototyping approach, it was decided to implement and evaluate a Tap&Map prototype during the collaboration with CIB. The prototype was later evaluated in two communities (Matoto and Sembola) that were located very close to the logging company's facilities.

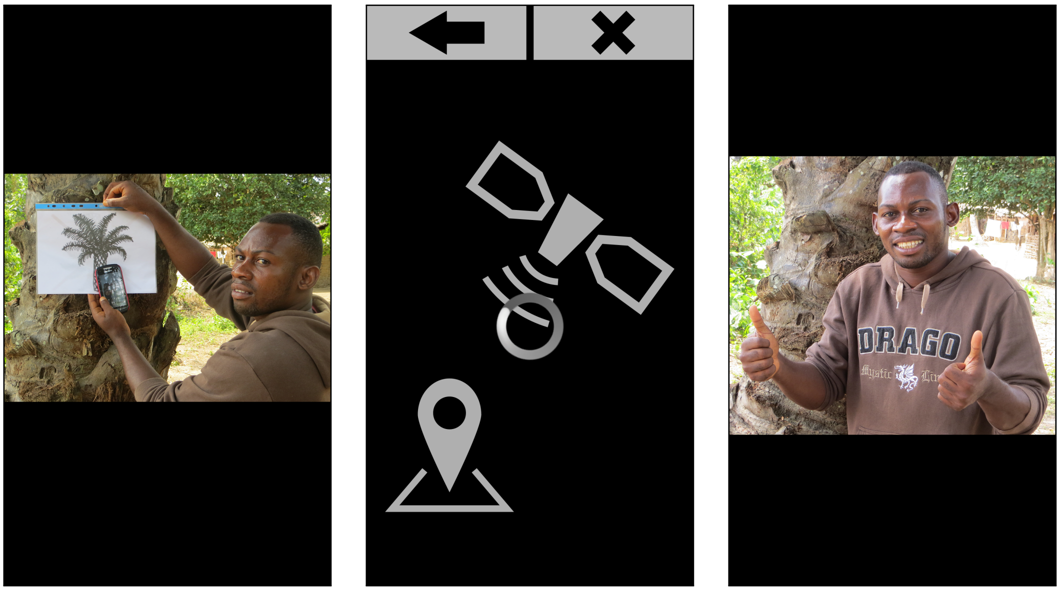
[7]The credits for the name go to Gill Conquest.

Thirty-two adult participants (15 males, 17 females) took part in the study, selected on a voluntary basis on the days of the evaluations. The majority had been present on the previous days during our introduction of Sapelli, but they had not participated in the audio feedback trials. They were aged between 18 and 61 years old (M=28.8, SD=11.4) and the majority were Mbendjele (87.5%), while 12.5% were Mikaya. With regards to education, 44% of the participants had no formal education, 47% had a primary school education, and 9% had a secondary education.

The printed cards that were used, were the same as those used for training purposes during the audio feedback trials (figure 8.11a). Since it was impossible to acquire NFC tags in the rainforest, it was decided to develop a prototype which imitated the functionality of Tap&Map. The Android application that was developed consisted of three simple UIs: (a) a start screen with a photo of one of the research assistants touching the phone on top of a card to demonstrate how the app works (figure 8.12a); (b) an interface imitating a GPS waiting screen, similar to the one used in Sapelli (figure 8.12b); and (c) a final screen with a photo of one of the research assistants giving a '*thumbs-up*' hand gesture to indicate that a point has been successfully recorded (figure 8.12c). The '*thumbs-up*' gesture was suggest by one of the research assistants when asked what would be suitable to indicate a correct observation, thus it was assumed that it would be appropriate for the participants.

As seen in the ICT4D literature (see section 5.2.2), paper-prototypes or low fidelity prototypes do not work well in this context. For that reason, it was decided that the Tap&Map prototype should be as functional as possible. In order for the application to feel as real as possible, a separate application it was developed to act as a controller. This app was installed on another phone, and controlled Tap&Map prototype remotely via Bluetooth. The remote application had only three buttons for selecting and changing the displayed UI on the Tap&Map prototype.

On the day of the evaluations, the FPIC process to introduce the project and the icons was followed, as explained in previous sections. After introducing the icons using the flashcards, the author did a demonstration around the village on how to map resources such as trees by selecting the appropriate card, placing the card on the tree trunk and then placing the phone on top of the card. A research assistant operated the Bluetooth remote app and changed the displayed UI on Tap&Map from the initial help screen to the GPS waiting screen, then slightly later to the success screen. Mapping abstract or larger resources, such as the village itself, proved more challenging since there was no single reference point. To demonstrate how to do this, the author walked to the centre of the village, selected the village card and held the card in the air while touching it with the phone.



(a) Start screen. **(b)** GPS waiting screen. **(c)** Confirmation screen.

Figure 8.12.: Prototype UIs for Tap&Map.

After the demonstration, the procedure of the evaluations was very similar to that followed in the audio feedback trials. The same five nearby resources were used and two participants were accompanied to each of the points, along with two research assistants. Since, working in pairs seemed to have a positive effect and helped participants to relax during the previous trials, the same structure was kept. The research assistants were responsible for video-recording the process, translating and explaining the tasks to the participants. As in the previous trial, the participants were asked to describe the point of interest in front of them. Then they were given a stack of shuffled cards and a mobile phone with Tap&Map loaded. The participants' task was to map the resources by finding and selecting the appropriate card, placing the card as close as possible to the resource, touching their phone on the card and waiting for the GPS screen and then the success screen to show. Meanwhile, the remote app switched the UIs (from the waiting screen to the GPS screen and finally to the success screen) to indicate that a complete observation had been performed. At this point it was noted whether the participants had successfully completed the task or not.

Tap&Map results

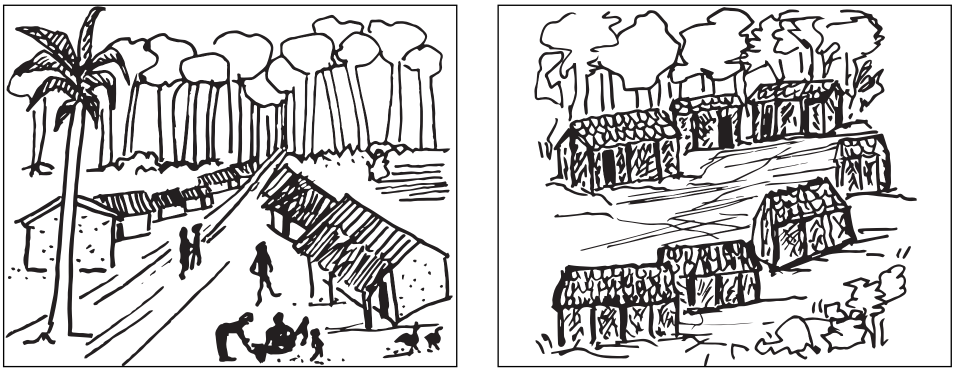
Over a period of two days, 32 participants completed 160 tasks using Tap&Map, with a success rate of 97.50%, and failing only on 4 tasks (table 8.4). During the interviews the participants were very enthusiastic about the Tap&Map prototype, and unanimously agreed that this version was faster, easier and more comfortable to use compared to Sapelli. Everyone agreed that they had no difficulties in selecting the appropriate icons and performing the tapping exercises. Indicatively, one Mbendjele woman said: '*I have never used a mobile phone in my life and I am so happy that it was so easy*'. A man said that he really liked the version with tapping cards and he volunteered to travel up to the next forest community through the rainforest and collect points with Tap&Map.

Table 8.4.: Tap&Map results relation to education and technology familiarity.

	Matoto, Sembola
Education level	
No formal education	44%
Primary school	47%
Secondary school	9%
Unknown[1]	0%
Technology familiarity	
Used mobile phone before	28%
Success rate	
Success	156 **(97.50%)**
Failure	4 **(2.50%)**
Number of Tasks	160

Note. [1]*Unknown* represents participants who stated that they had received some education but could not specify which level they had reached.

As depicted by table 8.4, the majority of participants had either no formal education or primary school education (91%), while 28% of the participants stated that they had used a mobile device before (feature or smart phone). Finally, all four of failed attempts with Tap&Map occurred when participants tried to map their village. In the scope of the project, participants could map their village and declare whether this was a Pygmies only village (figure 8.13a) or a Bantu village (figure 8.13b). In all four of instances, participants chose the wrong village icon, instead for example choosing a random icon in general, which suggested that they understood the process but could not distinguish between the icons. This was an indication that the icons symbolising Pygmies and Bantu villages respectively were problematic and had to be redrawn, rather than the process of using Tap&Map being ambiguous for them.



(a) Pygmies village. **(b)** Bantu village.

Figure 8.13.: Icons that caused confusion during Tap&Map.

8.5 Discussion

The collaboration with CIB and the local communities in CIB's concession, provided the appropriate environment to conduct structured usability evaluations of Sapelli and the different experimental features that had added to the platform to improve usability and user satisfaction, such as audio feedback and physical interfaces. This section discuss the results of the case study in terms of the two research questions. As in the previous chapters, it starts with the discussion of RQ 2 as it is more general and leads to the discussion on RQ 1.

8.6 RQ 2

The second research question of the thesis aimed to assess the challenges of designing, evaluating and deploying an ICT system for non-literate participants to capture their TEK.

One of the challenges, identified in the previous chapter, was conducting usability evaluations in a non-controlled environment – such as a community village in the middle of Congo Basin. As discussed, such evaluations come with multiple cultural differences, communications issues and logistical constraints. As noted in chapter 7, these results were broadly consistent with other ICT4D evaluations in similar contexts (Chetty and Chetty, 2007; Chetty and Grinter, 2007; Anokwa et al., 2009; Anokwa et al., 2012; Soares and Giesteira, 2015), but nevertheless suggested than an alternative methodology should be sought for experimenting in this context. One of these cultural differences, that was identified in the previous usability evaluations and was a major issue, was the different attitude these communities had towards one-to-one evaluations compared to western societies. Community members were highly cooperative and consequently bystanders would often help participants during their tasks. However, we wanted to establish a baseline of individual performance to be able to compare that with future releases and other experimental features. In addition, in participatory projects the goal was to provide community members with a number of phones and enable them to capture their local resources fast and efficiently, thus it was important to ensure that individual participants were understanding the process and were able to contribute in data collection efforts with valid and accurate data.

In this field trip, it was endeavoured to tackle the issue by establishing a strict protocol with the research assistants and giving them a detailed protocol on how and when to assist participants. Next, to avoid bystanders to assist or confuse the participants, it was decided to conduct the evaluation during a relaxed walk in the nearby forest. Of course, this approach had an obvious limitation of being time-consuming, since a single evaluation round lasted more than 30 minutes. However, the results were promising, since participants gave positive feedback regarding the evaluations and they did not seemed as stressed as they were in previous evaluations that took place in the centre of the village.

Equally, in the previous trials the use of hypothetical scenarios did not work well with participants, who were confused and unsure what actions were required. In this field trip, practical real-life tasks, such as mapping nearby resources, seemed to be more appropriate. At each of the tasks, participants were asked what the resource they were mapping was about and explain its significance. All participants were able to explain correctly what the collection point was, and why the mapping procedure was important for their community, which signified that they understood the mapping process and what the task they had to perform was.

Although this approach was conducted only in one region and in regard to data collection, the results could be generalised in other areas and contexts when evaluating ICT artefacts. This case study suggests that in ICT4D contexts, were literature suggests that participants cannot relate to abstract scenarios, real-life tasks should be employed for the evaluation of the suggested ICT systems.

In terms of usability evaluation methodologies, this study's observations support the idea that due to lack of experience and relevant vocabulary, methods such as 'think aloud' or asking for feedback on an interface are not applicable (Chetty and Chetty, 2007; Chetty and Grinter, 2007; Rodil et al., 2012). Alternatively, this case study demonstrated that a mixture of ethnographic approaches and observations, structured and semi-structured interviews and informal conversations can enhance the requirements gathering and provide insight on usability and user satisfaction of the platform. However, interviews and discussions with participants should also be taken into account with caution and linked to other forms of evaluation. It was observed that participants due to cultural differences tend to not provide negative feedback regarding the prototypes as this could be considered impolite (Mitchell, 1965; Bulmer and Warwick, 1993; Jones, 1993; D'Ambruoso et al., 2005; Chetty and Chetty, 2007; León et al., 2007; Anokwa et al., 2009; Glick, 2009; Dell et al., 2012), therefore the results of the interviews should be cross-referenced to other forms of evaluation (Chetty and Grinter, 2007; Anokwa et al., 2009). This was especially true in this case study with participants that performed poorly on the evaluations, when they asked about the prototype, they replied that it was very easy and convenient for them to use. In this case study, the interviews were also linked to the evaluations via the tasks and the internal logging of the application.

8.7 RQ 1

The first and primary research question of the thesis, explored the appropriateness of decision trees as an interaction mode for ICT systems for non-literate participants to capture TEK.

In terms of usability and user interaction, in this study three interfaces were evaluated for participants to overcome the literacy barrier and enable them to engage in participatory monitoring activities: pictorial decision trees; decision trees with audio feedback; and physical interfaces.

In general, pictorial decision trees constitute a fast and effective method for navigating through classification structures. Each decision tree represents one unique question, and chaining multiple trees allows participants to quickly answer a full survey. However, as shown in our results (both in the previous chapter and this case study), decision trees are not a universal solution. In this case study, it was demonstrated that community success rates vary from 60% to 85% and seem correlated with the average level of education or phone experience. For instance, in the evaluations taking place in the villages of Gbagbali and Kabo, two remote communities with lower average levels of education and access to technologies, the success rate of working with decision trees was 63.3%; while in Matoto and Sembola, which are communities with higher average levels of education, participants achieved success rates of 84.1%. These findings concur with other studies in the HCI4D area, which illustrate that non-literate participants have difficulties when it comes to abstract structures (see chapter 4). Interestingly, this contradicts the results of the literature in ICT4D, where in many initiatives, decision trees were employed and used by non-literate or semi-literate communities (see section 4.1.2). Finally, this suggests that decision trees should be used only after a close examination of the community and understanding the literacy levels amongst participants.

The second interface that was trialled, was decision trees complimented with audio feedback that explains through pre-recorded audio clips, in the local language, the meaning of each icon to the participant. While research in similar context suggests that audio had a significant improvement in accuracy (Parikh and Lazowska, 2006; Parikh et al., 2006), as shown by this case study's results, the audio feedback feature resulted in a slight, but not statistically significant, improvement in participant's average accuracy. What is interesting is that the majority of the participants preferred to use the audio feedback version, even though it did not significantly improve their performance. Speaking their own language, the device was able to entertain, reassure and verify the participant's choices, which it is believed that could lead to higher engagement with the project. Therefore, this case study illustrated the importance for audio interfaces, especially in the early stages of a project and during training sessions, to engage with the community and potentially reduce their learning curve. Audio feedback can be likened to '*training wheels*' that ensure participants feel comfortable and safe during training. Out of the 48 participants that trialled the audio feedback version, only two preferred the version without audio, the first participant was comfortable enough without audio and stated that he did not need it, while the second claimed that the audio prompt was very distracting for him, since he already knew the answers. This also reveals one of the limitations of audio feedback that for more experienced participants, audio feedback could become distracting or annoying and project managers should carefully use it depending on the needs and abilities of the participants. Another limitation, is the need to record audio prompts in the local language for all the UI elements within each screen. This introduces an important challenge of creating, modifying and maintaining projects that require audio feedback. Finally, analysis on the Sapelli logs suggests that participants using the audio feedback are on average slower to complete their observations, when compared to the non-audio version (figure 8.9).

Finally, this thesis also conducted evaluations of prototype, physical, tangible interfaces that proved to be more appropriate in scenarios where participants have minimal or no formal education or familiarity with technology. As the results indicate, physical interfaces provide comprehensible links between participants' knowledge, the real world and digital interfaces. This leads to higher levels of confidence and performance, and enhances the overall user experience. However, Tap&Map comes with a number of logistical issues of designing, printing and administrating a series of cards equipped with NFC tags. This requires local intermediaries to invest in both purchasing the devices and the cards per community, which could prove time-consuming and costly. In addition, an assemblage of cards is easier to be misplaced or lost when compared to a single smartphone that Sapelli requires.

However, all the suggested solutions have shortcomings and limitations. The options offered for data collection, in all of the interfaces, are strictly predefined during the design phase of the project or survey. In other words, users are restricted to the icons offered in a Sapelli survey, or by the NFC cards they are given for use with Tap&Map. This limitation means that a monitoring project should be regularly followed-up and continually adapted to match all the stakeholders' needs and requirements. Next, the questions to be answered are not directly apparent, but are implied to the user by the options provided as answers. Audio feedback can tackle this limitation by speaking out loud the question to the participants. This could be very beneficial during training sessions and the first stages of a project, until participants feel confident enough with the questions. Lastly, the UIs we have evaluated target simplicity and do not offer any direct feedback to participants in terms of the data collected, i.e. number of points, etc. However, it was out of the scope of this thesis given the time constraints to investigate tools and methodologies to enable visualisation, analysis and editing of spatio-temporal data in ways intelligible to local communities.

8.8 Summary

This chapter discussed the effort to collaborate with the logging company CIB and develop a tool that would enable communities into the company's concession to map and tag their resources as valuable and important in order to be removed from future logging sessions (section 8.1).

In early 2015, four communities in the Republic of the Congo, in CIB's concession, were visited to trial two experimental Sapelli modules, the '*audio feedback*' and '*physical interfaces*' that we hoped to resolve issues with the interpretation of icons, the overall hierarchical structure of a decision tree and the navigation metaphors used in Sapelli (left/right arrows, cancel icons etc.). Audio feedback would sequentially explain each item on the Sapelli screen by playing back pre-recorded audio clips in the local language, while physical animations would eliminate categorisation and abstraction issues.

While in the field, the results of audio feedback showed a slight but not significant improvement in accuracy (section 8.4.1). Although the results were not as positive as hoped in terms of accuracy, they showed an important impact on user experience and user preference, with audio feedback to be by far the most preferable option when participants were asked which version they would choose to use. Physical interfaces, on the other hand, were the most promising in terms of accuracy, since they had a success rate of 97.50% (section 8.4.2).

In terms of user interaction, this case study shows that all three different interfaces can and should be used depending on the users' needs and abilities. Pictorial decision trees are suggested as an effective method for semi-literate participants, without and with audio feedback for enhancing the user experience. Audio feedback could also be a vital part of training sessions until participants are experienced enough to disable it. Finally, physical interfaces are proposed for participants with minimal or no formal education for improving their confidence and performance.

9 Discussion

This concluding chapter discusses the experiences of working with local communities in LICs along with a discussion on the key findings of the thesis in relation to the literature. The chapter opens by restating the research questions (section 9.1), followed by two sections that discuss the results in relation to the two research questions of the thesis (sections 9.2 and 9.3). Then this chapter moves on exploring the strengths and limitations of this research (section 9.4), followed by its implications and contributions (section 9.5).

9.1 Restating the research questions

The research undertaken in the present thesis attempted to contribute in the resolution of sustainable development – one of the most significant, worldwide and pressing issues, as identified by UN in their MDGs and SDGs (see chapter 2). As explored in chapter 2, there is a growing imperative to record and protect TEK, as it is recognised as a promising solution to achieve long-term and sustainable management of ecosystems (Berkes, 2012; Ehrlich and Ehrlich, 2012; Jensen et al., 2012; Bonney et al., 2014). Local and indigenous communities around the world, possess a rare and complex understanding of their territory and the wider vision for this research was to provide the technological means to support them to share and apply their TEK and their knowledge of local environmental conditions using scientifically accepted methods that could lead to improvements in environmental governance and social-environmental justice (West et al., 2006; Raftree and Nkie, 2011; Lewis, 2012b). Thus, the general research agenda that is driving this research is:

> *How can ICT be applied to enable the collection of TEK to increase environmental sustainability?*

In the wider area of sustainability and data collection of TEK, this thesis narrowed the research focus on the usability of the suggested ICT tools to gather TEK and a literature review was conducted in the areas of ICT4D and HCI4D to explore suggestions and solutions regarding the design and evaluation of data collection tools with communities that are not familiar with technology (see chapter 4).

However, as explored in chapter 4, there seems to be a gap and contradiction between ICT4D and HCI4D in regards to the UI and especially to the appropriateness of decision trees. On the one hand, ICT4D practitioners and researchers report success stories from the field, while on the other, HCI4D researchers support the argument that due to the abstract nature of decision trees, they are not applicable for non-literate user groups (see section 4.5). Hence, this thesis aimed to explore the advantages and limitations of decision trees when employed as user interfaces on mobile devices to permit non-literate forest people to capture environmental data and focused on three aspects of the problem:

- The appropriateness of decision trees and their abstraction and complexity (see section 4.5);
- The use of other sensory information to support decision trees such as audio interfaces (see section 4.4);
- The use of physical objects to support data capture for TEK (see section 4.4).

Therefore, more formally, the RQ of this thesis is:

RQ 1 **Are pictorial decision trees an appropriate interaction style for non-literate communities in Central Africa to capture TEK?**

Additionally, as presented in section 5.2.2, methodologies that are very popular in the discipline of HCI such as UCD, and although being regularly employed in HCI4D scenarios (Roman and Colle, 2002; Colle, 2005; Medhi, 2007; Gruijters and Blake, 2008; Lalji and Good, 2008; Devezas et al., 2014), come with known difficulties. The lack of literacy and lack of computer skills amongst the participants, present communication issues since participants cannot express requirements, goals and functionalities in terms of ICT systems (Teka et al., 2016). In addition, researchers argue that users in ICT4D projects usually lack the experience to comment or suggest alterations, or to contribute in participatory exercises (Winschiers, 2006; Chetty and Chetty, 2007; Chetty and Grinter, 2007; Winschiers-Theophilus, 2009; Rodil et al., 2012). Hence, this research provided the ideal opportunity to reflect on the process of designing and evaluating ICT tools with decision trees and make an additional contribution to science. As a result, to address the above research question RQ 1, this thesis also explored an answer to the following sub-question:

RQ 2 **What are the challenges in designing a system that incorporates pictorial decision trees for non-literate people living in Central Africa to capture TEK?**

The following sections discuss the results for the two research questions by comparing the key findings to the existing literature and demonstrating the importance of the findings.

9.2 RQ 1

The first and primary research question of the thesis explored the appropriateness of decision trees as an interaction mode for non-literate participants. The key findings are summarised in box 3 and discussed in the rest of the section.

Box 3 Key findings for RQ 1

General

- **Pictographs** are appropriate to represent various measurements, environmental parameters, or local observations to be made, as they proved to be efficiently recognised by participants, for example when showed on flashcards, or when participants were asked about the meaning of a single icon on a UI.

Pictorial decision trees

- Decision trees **proved to be inappropriate** for non-literate participants.
- The performance rates of operating decision trees proved to be correlated to the **literacy levels** and spanned from 60% to 85%.
- The performance rates of operating decision trees revealed **no** particular **correlation between gender and age**.
- **Categorical icons** proved to be inappropriate and problematic for non-literate participants.
- **Navigational icons** proved to be inappropriate and problematic for non-literate participants.
- The overall **hierarchical structure** and the process of navigating via a decision tree proved to be inappropriate for illiterate or non-literate participants.
- In cases of **semi-literate participants**, decision trees proved to be more effective and fast to operate compared to alternatives such as trees with audio feedback or physical interfaces (success rates of 85% and 2 seconds faster than audio feedback).

Audio interfaces

- They provide **no significant improvement** in performance rates.

- They proved to **increase** participant's **satisfaction**, as they were the preferred method due to being reassuring, pedagogic and entertaining for participants.
- They proved to be **irritating and disturbing** for experienced participants.
- They provide **useful information** about the **questions being imposed** in each screen as they read aloud the question.
- They proved **helpful in training sessions**, since they increased participants' satisfaction.
- They come with an **increased logistical overhead** of recording and maintaining projects that require audio feedback.

Physical interfaces

- They massively **increase participants' performance** (success rates of 97.50%).
- They proved **appropriate** also for **participants with no literacy** and ICT familiarisation.
- They effectively **remove categorisation and abstraction** that proved to be inappropriate for non-literate participants.
- They increase participants' **confidence** and **satisfaction**.
- They come with an **increased logistical overhead** of creating and managing NFC cards.

Limitations of evaluated interaction modes

- All evaluated methods come with **predefined options** (either icons or cards) and do not provide the participants with an option to record additional information that they might regard as important.
- The **questions are not explicit** but they should be guessed by participants given the available answers.

General

As mentioned in the literature review (chapter 4), language and literacy are major barriers to the use of modern technology and mobile devices (Chipchase, 2005; Chipchase, 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2009; Chaudry et al., 2012; Kodagoda et al., 2012), as most UIs heavily depend on textual and numerical information. Numerous studies have attempted to identify guidelines, recommendations and principles for designing more effective UIs for semi or non-literate users and propose the use of interfaces free of textual and numerical information (Grisedale et al., 1997; Huenerfauth, 2002; Shakeel and Best, 2002; Ghosh et al., 2003; Parikh et al., 2003; Chipchase, 2005; Lewis and Nelson, 2006; Medhi et al., 2006; Bhamidipaty and Deepak, 2007; Sherwani et al., 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2011). In the context of ICT4D and HCI4D, researchers experiment with colours, symbols and icons to avoid textual components (Grisedale et al., 1997; Huenerfauth, 2002; Ghosh et al., 2003; Parikh et al., 2003; Medhi et al., 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008), while others propose the use of rich media (Gandhi et al., 2007; Medhi et al., 2009; Ladeira and Cutrell, 2010; Medhi et al., 2011).

One interesting finding of this research is that **pictographs**, especially when they were designed in an iterative process with communities, were appropriate to represent various measurements, environmental parameters, or local observations to be made. In all case studies, such pictographs were easily and efficiently recognised by participants when showed on flashcards, or when participants were asked about a single icon on a UI. This aligns with the literature that suggests the use of icons to represent different actions on UIs. What was surprising was that, pictographs that represented abstract concepts such as categories were not received well by non-literate participants, although they were co-designed with their active participation. This finding suggests that pictographs should be carefully selected or designed in such contexts to represent concrete measurements, environmental parameters, or observations, while abstract concepts should be avoided.

Pictorial decision trees

In general, pictorial decision trees constitute a fast and effective method for navigating through classification structures. Each decision tree represents one unique question, and chaining multiple trees allows participants to quickly answer a full survey. Since many studies conducted in the context of ICT4D and HCI4D highlight the importance of text-free interfaces when designing for non-literate or illiterate user groups (Grisedale et al., 1997; Huenerfauth, 2002; Shakeel and Best, 2002; Ghosh et al., 2003; Parikh et al., 2003; Chipchase, 2005; Lewis and Nelson, 2006; Medhi et al., 2006; Bhamidipaty and Deepak, 2007; Sherwani et al., 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2011), pictorial decision trees were employed in ICT4D projects to allow participants to collect various types of data (Liebenberg et al., 1999; Lewis, 2007; Liebenberg, 2011; Lewis, 2012b; Liebenberg et al., 2017). However, as explored in chapter 4, there seems to be a gap and contradiction between ICT4D and HCI4D in regards to the UI and especially to the appropriateness of decision trees. On the one hand, ICT4D practitioners and researchers report success stories from the field, while on the other, HCI4D researchers support the argument that due to the abstract nature of decision trees, they are not applicable for non-literate user groups (see section 4.5).

This thesis aimed to explore the advantages and limitations of decision trees and evaluated them across three case studies and with a number of different forest and agricultural communities in the Congo Basin (see chapters 6 to 8). Surprisingly and although researchers advocate for the use of pictorial icons in different UIs, the findings of this thesis reveal that decision trees and text-free UIs are not a universal solution and by simply replacing textual elements with equivalent icons will not lead necessarily to success. On the contrary, as this research revealed in chapter 8, the community performance rates vary from 60% to 85% and seem correlated with the average level of education. For instance, in the evaluations in Gbagbali and Kabo, two remote communities with lower average levels of education, the success rate of working with decision trees was 63.3%; while in Matoto and Sembola, which are communities with higher average levels of education, participants achieved success rates of 84.1% (see chapter 8).

Although a branch of HCI advocates that usability should be universal and that systems should be designed to be accessible and usable by everyone (Shneiderman, 1997, 2000), these findings further support the idea that there is no universal, or 'one-size-fits-all', solution and ICT-related initiatives should be adapted to local contexts and needs (Day and Greenwood, 2009; Unwin, 2009). As demonstrated, different communities depending on their literacy level and their technology familiarisation performed differently when using the prototypes. Therefore, usability should be adapted depending on the abilities of participants and their requirements.

Interestingly, the findings on the appropriateness of pictorial decision trees contradict the results of the literature in ICT4D, where in many initiatives, decision trees were employed and used by non-literate or semi-literate communities (see section 4.1.2). This finding suggests that decision trees should be used only after a close examination of the community and understanding the literacy levels amongst participants.

Recently, a number of studies highlighted that lack, or absence, of education has an impact on the development of cognitive abilities such as conceptual abstraction and categorisation (Katre, 2006; Linden and Cremers, 2008; Medhi et al., 2010; Brown et al., 2012; Medhi et al., 2013). In studies involving illiterate people in India, Medhi et al. (2013) found that underdevelopment of skills such as conceptual abstraction and categorisation may explain why non-literate users perform worse than literate users when navigating UIs even when they are text-free (Medhi et al., 2010; Medhi et al., 2010; Medhi et al., 2012; Medhi et al., 2013). Brown et al. (2012), suggest that decision trees (and hierarchical menu structures) in combination with abstract icons are too complex for illiterate people and pose a major challenge. Prasad et al. suggest that differences in mental models, due to cultural differences, prevented non-literate users in rural India from understanding abstract concepts such as the 'postcard' metaphor, where the service of email is analogised with a postcard being sent by post (Prasad et al., 2008). Finally, Walton et al., in studies in South Africa, discovered usability difficulties when users were presented with hierarchical information structures (Walton et al., 2002).

The above literature aligns with the findings of this research, where it was revealed that pictorial decision trees are not appropriate for non-literate participants. The major identified issues with decision trees were (a) the use of **categorical icons** that were interpreted literally by participants and were confusing, (b) the overall **hierarchical structure** in combination with the abstract **navigational icons** posed great challenges to participants. The above literature on abstract thinking, could explain the poor performance of participants in particular tasks. Additionally, over the past century, a significant increase on human performance on IQ tests was revealed in different parts of the world (Flynn, 2009). This phenomenon is named the '*Flynn effect*' after James Flynn who had an essential contribution in recognising, studying and measuring it (Flynn, 2009). Amongst the proposed causes, Flynn suggests that the increase is not an actual increase in intelligence rather than an increase in abstract problem solving (Flynn, 1987), which could be partially justified by improvements in education (Neisser, 1997; Marks, 2010). In the same vein, Neisser (1997) demonstrated that, on average, children who received no formal education for a period of time, had a decrease of six IQ points per year. Hence, it seems possible that the poor performance that was noticed in some participants is related to the lack of formal education, and therefore the lack of the abstraction and problem solving skills, which are required to operate a structure such as decision trees.

Yet this does not mean that pictorial decision trees are not appropriate to be used in projects where forest and agricultural communities are involved. As demonstrated, in many cases these interfaces offer a fast and efficient method for data collection, when used by **semi-literate participants**. Due to the limited time in the field, the training sessions and the subsequent evaluations were also limited. It would be interesting to explore the role of training in the performance of participants, as training could be likened to a form of formal education and it could improve participants' abstract thinking. Finally, the second of the MDGs was aiming to achieve universal primary education by 2015, while the fourth of the SDGs is aiming to improve the quality of education worldwide by 2030 (see section 2.1). To date, one out of five adults worldwide has no access to education (UIS, 2013), but this is steadily improving since the establishment of the MDGs. A 2015 UN report shows an increase in primary school enrolment in LICs, decrease in primary school drop-outs, drastic improvements in primary school education in parts of Africa and global increase in literacy amongst the youth (MDG Monitor, 2015). Therefore, there is a basis for optimism that as literacy levels increase, due to the realisation of the SDGs goals, this will result in higher success rates in data collection projects where pictorial decision trees are employed. Meanwhile, the other two suggested interaction modes, audio feedback and physical interfaces, alleviate some of the problems of decision trees and can be used in areas of high illiteracy levels.

Audio interfaces

As mentioned in the literature review (chapter 4), the use of auditory icons has a positive impact on factors such as learnability, memorability and performance (Edworthy and Hards, 1999; Ulfvengren, 2003; Bonebright and Nees, 2007; Garzonis et al., 2009a,b). Additionally, the use of additional sources of information (for example augmenting a UI with more modalities such as audio) can reduce the 'cognitive load' on participants (Jeung et al., 1997; Menelas et al., 2010; Lim et al., 2013). In ICT4D projects, audio clips recorded in the local language have been employed by researchers to assist rural users in India to perform micro-finance transactions (Parikh and Lazowska, 2006; Parikh et al., 2006). Similarly, Medhi et al. (2006) used audio clips in applications targeting low-literate users to access job seeking information and map navigation clues on a digital map. Other examples of audio recordings used in ICT4D projects, include the use of SDS where the user has to call a telephone number and follow the instructions to get access to the provided information (Plauche et al., 2006; Plauché and Prabaker, 2006; Sherwani et al., 2007; Agarwal et al., 2009; Grover et al., 2009; Sherwani et al., 2009; Patel et al., 2010).

Since audio and SDS have shown promising results, it was hypothetised that augmenting decision trees with audio cues, would reduce the cognitive load on participants and potentially increase their abstract problem solving. Surprisingly, no significant differences were found in terms of participants performance when they were employed in the context of this thesis.

However, another interesting finding is that the majority of the participants preferred to use the audio feedback version, even though it did not significantly improve their performance. Speaking their own language, the device was able to entertain, re-assure and verify the participant's choices, which it is believed that could lead to higher engagement with the project. The third case study of the thesis (chapter 8) illustrated the importance for audio interfaces, especially in the early stages of a project and during training sessions, to engage with the community and potentially reduce their learning curve. Audio feedback can be likened to '*training wheels*' that ensure participants feel comfortable and safe during training. Out of the 48 participants that trialled the audio feedback version, only two preferred the version without audio, the first participant was comfortable enough without audio and stated that he did not need it, while the second claimed that the audio prompt was very distracting for him, since he already knew the answers. This also reveals one of the limitations of audio feedback that for more experienced participants, audio feedback could become distracting or annoying and project managers should carefully use it depending on the needs and abilities of the participants.

Another identified limitation was the need to record audio prompts in all of the local languages for all the UI elements within each screen. Given that in the Congo basin there are numerous communities that speak different languages or variations of the same language, this introduces an important logistical challenge of creating, modifying and maintaining projects that require audio feedback. These results are consistent with those of other studies that suggest that recording in such challenging environments comes with many difficulties such as background noise, recording taking considerably long time etc. (Plauche et al., 2006; Plauché and Prabaker, 2006).

Finally, analysis on the Sapelli logs suggests that participants using the audio feedback are on average slower to complete their observations, when compared to the non-audio version.

Physical interfaces

As presented in the literature review (chapter 4), physical interfaces are gaining recognition recently and are commonly referred as TUIs (Fitzmaurice et al., 1995; Ishii and Ullmer, 1997; Shaer, 2009; Jensen et al., 2012; Dijk et al., 2015; Zhou, 2015). Although still in their early stages, TUIs feel more natural to users due to the notion of 'affordance', which suggests that users have more possibilities for action in a given situation (Shaer, 2009), and 'embodied cognition' (Dourish, 2004; Hornecker and Buur, 2006; Antle, 2007; Fernaeus et al., 2008; Hornecker et al., 2008; Shaer, 2009; Zhou, 2015). Also, TUIs provide a link with the real world and as a result build on users' knowledge on how to interact with physical objects which in turn can improve participants' confidence (Rekimoto et al., 2001).

In terms of ICT4D and HCI4D, there are very limited examples of physical interfaces being used to provide non-literate users with interfaces for communicating with digital technology. Parmar et al. (2009) discusses the use of TUIs as a mechanism to access health information and report promising results. In a similar vein, Unnikrishnan et al. (2016) describe a tangible game for teaching underprivileged children in rural India and reports promising results.

This thesis endeavoured to investigate how physical interfaces can be linked with data collection projects in order to improve the process of data collection and participants' performance and satisfaction due to the increased affordances that they offer and the embodied cognition.

As the results indicate, physical interfaces led to higher levels of confidence and performance (success rates of 97.50%), and enhanced the overall user experience. These findings are aligned with the above literature that supported that physical interfaces can improve the overall experience for participants. In terms of data collection, physical interfaces proved to solve the categorisation and abstraction issues that pictorial decision trees were introducing. Interestingly, physical interfaces performed equally well amongst semi-literate and non-literate participants.

However, physical interfaces such as the Tap&Map system that was conceptualised in the third case study (chapter 8) comes with a number of logistical issues of designing, producing and maintaining a series of physical objects. For example in the Tap&Map scenario, a number of cards equipped with NFC tags has to be designed, printed and distributed to the participating communities. This requires local intermediaries to invest in both purchasing the devices and the cards per community, which could prove time-consuming and costly. In addition, an assemblage of cards is easier to be misplaced or lost when compared to a single smartphone that a Sapelli app operating with pictorial decision trees requires.

Limitations of evaluated interaction modes

In this thesis, three different interactions modes where employed and evaluated (pictorial decision trees, decision trees augmented with audio feedback and physical interfaces), but all the suggested solutions have shortcomings and limitations.

The options offered for data collection, in all of the interfaces are strictly predefined during the design phase of the project or survey. In other words, users are restricted to the icons offered in a Sapelli survey, or by the NFC cards they are given for use with Tap&Map. This limitation means that a monitoring project should be regularly followed-up and continually adapted to match all the stakeholders' needs and requirements.

Next, the questions to be answered are not directly apparent, but are implied to the participant by the options provided as answers. Audio feedback can tackle this limitation by speaking out loud the question to the participants. This could be very beneficial during training sessions and the first stages of a project, until participants feel confident enough with the questions.

Lastly, the UIs we have evaluated target simplicity and do not offer any direct feedback to participants in terms of the data collected, i.e. number of points, etc. However, it was out of the scope of this thesis given the time constraints to investigate tools and methodologies to enable visualisation, analysis and editing of spatio-temporal data in ways intelligible to local communities.

9.3 RQ 2

The second research question of the thesis aimed to assess the challenges of designing, evaluating and deploying an ICT system for non-literate participants to capture their TEK. The key findings are summarised in box 4 and discussed in the rest of the section.

Box 4 Key findings for RQ 2

General

- Difficulty in **finding and establishing collaborations** with local communities and intermediaries.
- Difficulty for researchers to **visit the research area** in a short notice.

Contextual understanding

- Capturing **requirements via a proxy** proved to have many advantages such as being low-cost, fast and effective.

Evaluation methods

- **Remotely evaluating** the ICT system via text logs proved to be an effective method as it indicated navigational and categorisation issues.
- Although **evaluating** the system via a **proxy** can be fast and low-cost, it proved to be inadequate to identify major usability issues such as navigational and abstraction differences etc.
- **Cognitive walkthroughs** via local experts can identify early usability issues but proved inadequate to identify major usability issues such as navigational and abstraction differences etc.
- Ethnographic approaches such as **observational evaluations** proved appropriate to provide a firm understanding of participants and identified major usability issues.
- **Structured usability evaluations** proved to have a list of logistical and practical challenges.
- Within structured usability evaluations **hypothetical scenarios** proved to be inappropriate for non-literate participants.
- Within structured usability evaluations, **practical tasks** (e.g. walk in the forest and mapping trees) proved to be appropriate and helped participants to relax and enjoy the tasks.

- **Semi-structured interviews** proved helpful but also revealed that participants, due to cultural differences, tended to not provide negative feedback for the prototypes, such as their concerns or elements they found difficult to understand.

General

As seen in the literature, establishing relationships with intermediaries who have a sustained local presence, sufficient expertise in local conditions, and who are trusted by local communities is vital (Sein and Furuholt, 2009, 2012; Aal et al., 2014; Stevens et al., 2014; Therias et al., 2015). Such partnerships work to lend legitimacy to a project from the point of view of participants and other local stakeholders (Sein and Furuholt, 2009, 2012; Aal et al., 2014; Stevens et al., 2014; Therias et al., 2015). Without local partnerships it is extremely difficult to get access to such communities.

The intermediaries provided access to communities and allowed the research team to work with otherwise difficult to reach communities and often act as the eventual coordinators of the project. Hence, they bring their own requirements and expectations, and in some cases may be described as 'clients'. Consequently, our role in these multi-stakeholder projects is multifaceted. We act as community facilitators, logistics planners, interface designers, software engineers, and ICT consultants.

As a result it is important to maintain an awareness that all intermediary stakeholders, including community members, are likely to have their own agendas that may fit to varying extents with the goals of an extreme citizen science project. Understanding and mapping these agendas is vital if the introduction of specially designed software is to have a positive and sustainable effect.

The above challenge, in combination with the difficulty for researchers to visit the research area in a short notice, due to logistical issues such as obtaining a travel visa and an invitation letter from local NGOs, adds another layer of complexity into conducting research in the area.

Contextual understanding

As presented in the literature review (chapter 4), acquiring a good contextual understanding provides a firm foundation for the success of any ICT project (Ross and Schoman, 1977; Wiegers and Beatty, 2013). Thus, the initial step in any software development life cycle model, and the cornerstone of the UCD approach, is the gathering of requirements through in-depth discussions and interviews with all stakeholders who will use the system (Robertson and Robertson, 2012). Typically, a software engineer or a designer will interact directly with the stakeholders of the project in order to understand the context and their needs.

In the ICT4D area (see section 4.1.1), UCD is the most common approach for designing and evaluating digital technology and researchers initially endeavour to identify the problem by conducting interviews with stakeholders (i.e. community members, NGOs etc.), before designing and introducing their solutions (Chipchase, 2006; Bhamidipaty and Deepak, 2007; Medhi, 2007; Joshi et al., 2008; Chaudry et al., 2012). Moreover, lately there has been a paradigm shift in HCI in how usability evaluations are designed and conducted. Typically, evaluations were conducted in the isolated and restricted environment of labs, were users were focused on performing particular tasks and other distractions were minimised (Rogers, 2011). However, researchers in the field of HCI are abandoning their labs in favour of carrying out their evaluations in the physical setting of their users (Brown et al., 2011; Rogers, 2011; Chamberlain et al., 2012).

Although, 'in the wild' requirements gathering and evaluations are costly, take considerably more time and are very labour-intensive (Davies, 2005; Kjeldskov and Skov, 2014), they can also identify issues that are impossible to uncover on lab settings by providing a better contextual understanding to researchers. However, in the context of this thesis and given the difficulties as described in the previous section, a field trip for capturing requirements was not feasible to be organised. This, in combination with other researchers suggesting that users in ICT4D contexts lack the skills to provide feedback and describe their requirements in terms of ICT systems (section 6.2) required for alternative approaches. Alternatively, during the first case study a different approach was trialled were the initial list of requirements was drafted after a series of interviews with an anthropologist, who had a close collaboration with the local communities and acted as a proxy (figure 6.1b on page 101). In addition, the requirements were drafted by analysing the literature and similar ICT4D initiatives [such as Liebenberg et al. (1999), Liebenberg (2011), Lewis (2012b) and Liebenberg et al. (2017)].

However, this initial list of requirements had a numbers of limitations and bore the risk of being biased since only one representative of the communities (the anthropologist) was employed to extract the requirements. This proxy had the risk of not being representative for the communities as a whole. To mitigate that risk, as the research progressed, more anthropologists, with local knowledge, were interviewed and later two field trips were arranged for the author to amend the list of requirements by observing the participants and conducting interviews with them.

Also local stakeholders such as NGOs and representatives from logging companies were interviewed.

One unanticipated finding was that the initial list of requirements was only slightly amended during the following two case studies. This indicated that the approach of capturing requirements via a proxy was adequate and proved to have many advantages. For example it was fast, effective and low cost.

Evaluation methods

Remotely evaluating As noted in the previous section, one of the early identified challenges, was the logistical difficulties in visiting the research area for extracting requirements and evaluating the prototype. As a result, during the first case study, the prototype was evaluated via a proxy (research assistant) and via capturing text logs of user interaction. While text logs proved to be effective as a method and indicated some initial navigational and categorisation issues, evaluating via a proxy was not that promising as a method. Although evaluating via a proxy is a fast and low-cost method that could be employed to identify usability issues in early stages, it failed to identify major usability issues such as navigational issues and abstraction differences that emerged through observational evaluation, structured usability evaluations and interviews in the following case studies.

Cognitive walkthroughs This thesis also employed cognitive walkthroughs, in both the first and second case study, as a low-cost method to investigate the usability of decision trees before the research field evaluations. However, we argued that cognitive walkthroughs are very challenging when the participants are so different from the usability experts who conduct the evaluation. To tackle this, field experts that acted as proxies for the end users were employed for the conduction of the cognitive walkthroughts. Although, this was a very useful exercise to identify minor usability issues, as the results of the second case study demonstrated (section 7.5.2), it failed to identify other interaction challenges such as the navigational issues, abstraction differences etc. Therefore, despite the fact that they are easy to deploy and perform, cognitive walkthroughs should be used with caution. These results further align with the limited HCI4D literature that suggests that cognitive walkthroughs might have potential issues when employed in an ICT4D context (Chetty and Grinter, 2007).

Observational evaluations Ethnographic approaches such as observational evaluations proved appropriate to provide a firm understanding of participants and identified major usability issues. This aligns with the ICT4D literature where ethnographic observations are frequently employed (Tucker et al., 2007; Bidwell et al., 2011; Taylor, 2011; Frohlich et al., 2012; Hagan et al., 2012; Avgerou and Li, 2013; Densmore et al., 2013; Pucciarelli et al., 2013; Stam, 2014). Observations were employed primarily in the second and third case studies were 192 and 80 participants were observed using the prototypes respectively.

Structured usability evaluations As mentioned in the literature review (chapter 4), conducting evaluations in the field comes with a number of challenges such as cultural differences in terms of evaluations, interruptions by bystanders, noisy environments, time limitations etc. (Chetty and Chetty, 2007; Chetty and Grinter, 2007; Anokwa et al., 2009; Anokwa et al., 2012; Soares and Giesteira, 2015). The findings of this thesis are consistent with those of other studies and suggest that it is not feasible to conduct evaluations '*in the wild*' in the same way that are conducted in controlled environments. In our evaluations, participants were not used to be evaluated at an individual level and therefore participants asked and received assistance from bystanders, translators etc. This was interesting and demonstrated the community's preference to work together, since data collection is not an individual task, but a group task, where people can pass the phone to each other and discuss their results. During those evaluations, it would have been considered culturally offensive to stop people from collaborating and the usability evaluation was quickly adapted into an observation process. However, it was important to establish an individual baseline of performance in order to evaluate decision trees, or alternative interaction methods in the future. As a result, this suggested that an alternative methodology should be sought for conducting evaluations in this context.

In the third case study, it was endeavoured to tackle the issue by establishing a strict protocol with the research assistants and giving them a detailed protocol on how and when to assist participants. Next, to avoid bystanders to assist or confuse the participants, it was decided to conduct the evaluation during a relaxed walk in the nearby forest. Of course, this approach had an obvious limitation of being time-consuming, since a single evaluation round lasted more than 30 minutes. However, the results were promising, since participants gave positive feedback regarding the evaluations and they did not seemed as stressed as they were in previous evaluations that took place in the crowded centre of the village.

Hypothetical vs Practical tasks As noted, recent studies in HCI4D point out that low-literacy, illiteracy and non-literacy are usually the result of a lack of formal education and such people might also struggle with other cognitive tasks besides reading and writing (Katre, 2006; Linden and Cremers, 2008; Brown et al., 2012; Medhi et al., 2013).

The current study found that when conducting usability evaluations in that context, hypothetical scenario tasks (e.g. 'Suppose you are...') proved to be inappropriate and did not work well with non-literate participants. During the evaluation of the prototype in the second case study, participants struggled to understand or perform the tasks.

For the third case study, to help participants better understand the tasks and to avoid bystanders assisting participants who were struggling to perform the tasks, 'practical tasks' were used. In those participants had to use the evaluated prototype in real life, practical scenarios of e.g. mapping nearby forest resources as a part of a walk in the forest. These practical tasks proved to relax the participants and allowed them better understand the tasks.

Interviews Prior studies in ICT4D contexts have noticed that due to cultural differences, participants tend to not provide negative feedback regarding the prototypes as they consider this to be impolite (Mitchell, 1965; Bulmer and Warwick, 1993; Jones, 1993; D'Ambruoso et al., 2005; Chetty and Chetty, 2007; León et al., 2007; Anokwa et al., 2009; Glick, 2009; Dell et al., 2012). This is known as the 'courtesy bias', where respondents tend to give answers that they believe the interviewer wants to hear, rather than what they actually believe regarding the questions (Jones, 1993). As a result, researchers advocate for interviews to be cross-referenced with other forms of evaluation (Chetty and Grinter, 2007; Tucker et al., 2007; Anokwa et al., 2009).

The findings of this thesis agree with the findings of the mentioned studies, as in the two cases where interviews were conducted, it was noticed that participants tried to be polite and therefore provide 'polite' answers. This was especially true with participants that performed poorly on the evaluations, since when they were asked about the prototype, they replied that it was very easy and convenient for them to use. In order to mitigate that bias, the interviews were cross-referenced with other evaluations methods, such as the task evaluations and text logging with the application.

9.4 Strengths and Limitations

This section summarises the key strengths and limitations of this thesis in box 5 and discusses them in the rest of the section.

Box 5 Key Strengths and Limitations

Key Strengths

- Large **number of participants** even for traditional usability evaluations. Given the context and the difficulty of conducting research in the area, this is one of the largest usability evaluations in the given context.
- A large number of **different communities** (e.g. Pygmy, Bandu etc) in different areas were evaluated that endeavours to provide generalisability.
- Collaboration with **different stakeholders** to provide generalisability.

Key Limitations

- Participants' and research assistant's (as an observer) bias.
- Courtesy bias and social desirability.
- Language barriers.
- Different collaborations resulted to different decision trees. Hence, the three case studies did not compare the same structure across different participants.
- Although different communities were evaluated over different areas of RoC, more research in required to ensure applicability to other illiterate populations elsewhere e.g. India, Brazil etc.
- All evaluation took place with communities where the ExCiteS approach of introducing and training was applied. More research is required to evaluate communities without any training to explore how intuitive are the different suggested interaction modes (pictorial decision trees, audio and physical interfaces).

Strengths

In the literature, there have been many discussions regarding the ideal sample size when conducting usability evaluations but there seems to be no consensus (Hwang and Salvendy, 2010). On the one hand, Nielsen (1989) argues that 5 users are 'good enough' to identify the majority of usability issues (Nielsen, 2009, 2012), while on the other, Hwang and Salvendy (2010) argue for 10+ users and Schmettow (2012) argues that there is no 'magic number' and the sample size should depend on the project, since certain projects will require a greater number of participants.

As noted in previous sections, in ICT4D and HCI4D projects, establishing collaborations and engaging participants is one of the most important challenges. As a result, the small sample size seems to be one of the most common reported limitations in such projects (Anokwa et al., 2012; DeRenzi et al., 2012; Taylor, 2015; Ali et al., 2016; Katule et al., 2016). To tackle the sample size issue, in the current thesis a large number of participants was reached and employed. Given the context and the difficulty of conducting research in the area, this is one of the largest usability evaluations in the given context (see table 9.1).

Table 9.1.: Sample size per case study.

Case study 1:
- Four participants took part in training and evaluation sessions.
Case study 2:
- Observational evaluations in four communities with 192 participants (106 males, 86 females).
- Structured usability evaluations with 30 participants (16 males, 14 females).
Case study 3:
- Observational evaluations in four communities with 80 participants (39 males, 41 females).
- Audio feedback evaluations with 48 adult participants (24 males, 24 females).
- Physical interfaces evaluations with 32 participants (15 males, 17 females).

This thesis has also conducted research in different areas of the Republic of the Congo, where a number of forest and agricultural communities (such as Pygmies and Bandu) were visited. Across the three case studies of the thesis, six communities were visited (Attention, Gbagbali, Kabo, Longa, Matoto, Sembola), with many of them being visited more than once. These communities live in different parts of the country and have different lifestyles (e.g. forest, agricultural, settled communities etc.) and cultural background (e.g. Pygmies, Bantu etc.). However, the common denominator was the level of literacy, and more particularly the lack of literacy or ICT familiarisation. Hence, the large number of communities in combination with the key findings being consistent across communities, provides a solid ground for generalisability and transferability of the key findings of this research to similar contexts.

In addition, throughout the three case studies, we collaborated with different stakeholders such as NGOs and logging companies to collect different types of data, which demonstrated the technical feasibility of the approach. However, the adoption depends on the agendas and priorities of local stakeholders and policy makers. As noted, the case studies described in the thesis were pilot studies with no assurance for further deployments.

Although this research was conducted in the Republic of the Congo, the large sample of participants in the evaluations in combination with the fact that different communities were evaluated, provides solid ground for generalisability in the area of Congo Basin or extend to Central Africa, since the majority of local communities share many traditions and traits (see chapter 3). However, more research in required to ensure applicability to other illiterate populations elsewhere e.g. India, Brazil etc.

Limitations

As noted in previous sections, participants in ICT4D projects tend to avoid negative feedback as they consider this to be impolite (Mitchell, 1965; Bulmer and Warwick, 1993; Jones, 1993; D'Ambruoso et al., 2005; Chetty and Chetty, 2007; León et al., 2007; Anokwa et al., 2009; Glick, 2009; Dell et al., 2012). This is known as the 'courtesy bias', where respondents tend to give answers that they believe the interviewer wants to hear, rather than what they actually believe regarding the questions (Jones, 1993). As a result, researchers advocate for interviews to be cross-referenced with other forms of evaluation (Chetty and Grinter, 2007; Tucker et al., 2007; Anokwa et al., 2009). This in combination with participants' bias such as 'social desirability' and the potential bias from the research assistant who evaluated the first case study or the author in subsequent case studies, could negatively influence the validity of this research.

As already noted, in order to tackle these limitations e.g. as the 'courtesy bias' that was identified during interviews, different evaluations methods were applied and the results were cross-referenced. For example in the first case study, a protocol was provided to the research assistant to apply during the field visit, but also text logging was enabled. As presented in section 6.6, the results of the two methods showed inconsistencies and motivated further research and investigation. Similarly, in case studies 2 & 3, a set of methods was applied observational evaluations, evaluations via hypothetical and practical tasks, interviews and text logging. All these different methods allowed to tackle any limitations due to bias and improve the validity of the research.

This research was also limited by the language and communication difficulties. Finding good translators was a very important challenge when working in challenging environments where different local languages are spoken. In order to conduct research in the area, we often had to go through multiple steps of translation (e.g. English > French > Lingala > Mbendjele) (see figure 7.12 on page 140), with the potential for meaning to be lost, changed or added. For that reason, all user interactions and interviews were video-recorded for later analysis or re-translation if necessary. However, even that posed major challenges, since for example in the UK, only Jerome Lewis was known to be able to understand and translate from and to Mbendjele. This bears the risk of a biased interpretation of the observations and interviews. To tackle these, again different evaluation methods were applied, for example the fact that Sapelli was recording each user interaction to study participant's navigational patterns proved very useful. For instance, the interaction logging was vital in recognising that the navigational items were rarely used in Sapelli (see section 8.4).

Another limitation was the fact that the three case studies were collaborations with different stakeholders and subsequently the decision trees that were evaluated were different. Consequently, the results of the three case studies cannot directly be compared e.g. performance rates across different projects cannot be compared. However, the issues that were identified with pictorial decision trees (e.g. abstraction and navigational issues, categorisation icons being interpreted literally etc.) were present across case studies and therefore ensure greater validity of the findings.

Next, although different communities were evaluated over different areas of RoC and there is solid ground for generalisability in the Congo Basin and/or Central Africa, more research in required to ensure applicability to other illiterate populations elsewhere e.g. India, Brazil etc. Although the literature suggests that abstraction and categorisation are issues faced by non-literate participants in other parts of the world as well e.g. India (Prasad et al., 2008; Medhi et al., 2010; Medhi et al., 2010; Medhi et al., 2012; Medhi et al., 2013), South Africa (Walton et al., 2002) etc., it might be risky to assume the same findings regarding pictorial decision trees, audio and physical interfaces would be reproducible. Thus more research is required in different parts of the world to ensure that the same findings and implications apply universally.

Finally, being limited to the ExCiteS approach of introducing and training, it would be interesting to evaluate communities without any training to explore how intuitive are the different suggested interaction modes (pictorial decision trees, audio and physical interfaces). Additionally, due to the limited time in the field, the ExCiteS training sessions were also limited. It would be interesting to explore the role of training in the performance of participants, as training could be likened to a form of formal education and it could improve participants' abstract thinking. Therefore, an open question for further research could explore how consistent, prolonged training could impact participants understanding of pictorial decision trees.

9.5 Implications and Contributions

This sections summarises the key implications and contributions of this thesis in box 6 and discusses them in the rest of the section.

Box 6 Key Implications and Contributions

- **Pictographs are appropriate** to represent concrete measurements, environmental parameters, or observations for non-literate participants.
- Pictographs should be carefully selected or designed in such contexts to represent concrete measurements and **abstract concepts should be avoided.**
- In data collection schemes, in LICs, **pictorial decision trees should not be employed** for non-literate participants, especially at the first stages of a project.
- Similarly, in data collection schemes, in LICs, **physical interfaces should be preferred** for non-literate participants to gather TEK.
- **Pictorial decision trees can be employed**, after a close examination of the community and the literacy levels amongst participants.
- In data collection schemes, in LICs, **audio feedback** should be used **during training sessions** to improve engagement and participants' satisfaction.
- Similarly, audio should be used with caution with participants that are **highly trained** as it could become **irritating** and **disturbing**.
- The data collection projects should be closely **monitored**, regularly **followed up** and continually **adapted** to match all the stakeholders' needs and requirements.
- In developing ICT tools for LICs, capturing **requirements via a proxy** can have many advantages such as being low-cost, fast and effective.
- In developing ICT tools for LICs, **evaluating via a proxy** can act as a starting point but it cannot reveal major usability issues.
- In developing ICT tools for LICs, **remotely evaluating via text logs** can reveal major issues.
- In developing ICT tools for LICs, **inspection methods** such as *heuristic evaluations* and *cognitive walkthoughts* should be avoided or used with caution.

- In developing ICT tools for LICs, from the **test methods** existing in usability engineering, *thinking aloud* should be avoided, *interviews* should be used with caution, while *field observations* and *field evaluations* are the most appropriate for the given context.
- In field evaluations, in LICs, **practical** tasks should be used, while **hypothetical** scenarios should be avoided.

Perhaps the most significant finding of the thesis is that while pictographs are appropriate for non-literate participants, pictorial decision trees are not appropriate for them. The vast majority of participants had no issues understanding **pictographs** when displayed as flashcards or as single icons. However, pictographs imposed many challenges when introduced within pictorial decision trees, and especially when they represented categories or navigational icons. The overall hierarchical structure in combination with the abstract or metaphorical nature of certain pictographs posed great challenges to non-literate participants. Therefore, it is advocated that pictographs, that are co-designed with the communities, should be used, but pictorial decision trees should be avoided in cases where low-literacy or non-literacy prevails.

As the results of this thesis indicate that decision trees are not suitable, it is interesting to explore why the ICT4D community had a number of reports where decision trees deemed appropriate. One possible explanation is that due to the ICT4D researchers' intimate knowledge of the situation and their familiarity with the people that they work with, the learning process became implicit or tacit and they didn't notice the issues of decision trees. Another possible explanation derived from later 'pers. comm.' with Lewis revealing that some people are better at using decision trees. Lewis's evaluations were conducted with a very small sample of community members that he was in close collaboration with and therefore already familiar with his approach, which could explain the very promising results. While in this thesis, the appropriateness of decision trees was evaluated against a broad number of participants, coming from different backgrounds.

Alternatively, **physical interfaces** and **audio interfaces** should be used to improve participants performance and satisfaction. For example, physical interfaces proved to dramatically increase participants' performance, while they are not correlated with literacy levels, age or gender. However, physical interfaces come with many logistical issues of designing and managing physical objects, while they also have a negative impact on efficiency (time needed for a participant to complete a task). Audio interfaces significantly increase participants' satisfaction and subsequently they can increase their engagement with the project. As reviewed in section 4.2, usability and user satisfaction play an important role in accepting and adopting a new technology. In the case of community mapping, user satisfaction can also impact the validity and results of the project. Hence, audio feedback can positively impact the training and mapping sessions, since it provides the participants with a playful and comforting system. However, audio interfaces do not have an impact on participants' performance, they negatively influence efficiency and can be annoying for highly trained participants.

Finally, data collection schemes should shift regularly depending on users needs and requirements. However, all the suggested solutions have a notable limitation that the options offered for data collection are strictly predefined during the design phase of the project or survey. In other words, participants are restricted to the icons offered in the pictorial decision tree survey, or by the NFC cards they are given for use with a physical interface, without having the option to make an '*other*' observation. This limitation means that a monitoring project should be regularly followed-up and continually adapted to match all the stakeholders' needs and requirements. If participants are unable to capture what they believe to be important, they might lose interest for the project or this might cause friction between the community and the different stakeholders.

In terms of contextual understanding & evaluation methods, the most compelling implication is that given the very challenging context of working in LICs, the initial capturing of requirements can take place by employing a proxy with a firm understanding of the context, the issues and the challenges. Next, in terms of evaluation, evaluating via a proxy can be problematic; evaluating via text logs can reveal a list usability issues; inspection methods should be used with caution and their results should be cross-referenced with other methods. Finally, from the list of **test methods** available to researchers, this thesis showed that *thinking aloud* should be avoided; *interviews* should be used with caution; while *field observations* and *field evaluations* are the most appropriate for the given context.

9.6 Summary

This chapter discussed the results of this thesis in relation to the two research questions that were set up at the beginning of the opening chapter and argued the importance of the results for the ICT4D and HCI4D disciplines. It is vital to point out that this research demonstrated that while pictorial decision trees are not appropriate for non-literate participants, when it comes to data collection, it also proved that other forms of interaction are. Thus there is potential for ICT tools to be developed with non-literate forest people in mind and enable them to participate in data collection schemes that target to improve sustainability in their local environment.

10 Summary and Future Work

This concluding chapter provides an overview of the research conducted (section 10.1) and wraps up the thesis (section 10.2). Finally, it presents future research suggestions and directions related to this work (section 10.3).

10.1 Research Overview

This research started with the realisation that sustainable natural resource management is a fundamental challenge that requires the active involvement of local and indigenous communities that possess deep understanding of their local environment (such as TEK) and can better contribute in its management and protection (see chapter 2). Given the scale of the issue of sustainable development and the inadequacy of existing paradigms it is clear that there is a need for interdisciplinary approaches to tackle the issue. As a result, this research has been conducted as part of work carried by the ExCiteS research group (see chapter 5).

In the wider area of sustainability and data collection of TEK, this thesis narrowed the research focus on the usability of the suggested ICT tools to gather TEK. For that reason, a literature review was conducted in the areas of ICT4D and HCI4D to explore suggestions and solutions regarding the design and evaluation of data collection tools with communities that are not familiar with technology (see chapter 4). However, this research found a gap and contradiction between ICT4D and HCI4D in regards to the UI and especially to the appropriateness of decision trees for data collection of TEK (see chapter 5). Therefore this research embarked on answering the following research question '**Are pictorial decision trees an appropriate interaction style for non-literate communities in Central Africa to capture TEK?**'.

Within ExCiteS, an AR approach was followed for collaborating with different indigenous communities and stakeholders. AR was employed due to its democratic nature and the active involvement of communities in the problem definition and resolution (see section 5.2.1). From a methodological standpoint, this individual research, conducted within ExCiteS, was mostly related to the fields of ICT4D as the primary question to be explored was whether decision trees 'work'. Therefore, it followed an engineering approach of problem solving and employed usability engineering methods to evaluate the solutions (see chapter 5).

Within that context, this thesis consisted of three case studies, all taking place in the RoC and focusing on enabling local communities to participate in socio-environmental monitoring schemes. These case studies provided the opportunity to conduct research on the appropriateness of decision trees as UIs to capture geographical data in order to support these schemes. The three studies were themselves independent case studies and were conducted in collaboration with different communities and stakeholders. As a result, each case study had different requirements but they were highly connected since the core challenges and goals were similar.

10.1.1 Case study 1: Participatory monitoring of poaching

The first case study of the thesis was presented in chapter 6 and endeavoured to introduce forest communities in the Republic of the Congo to a mobile platform to collect poaching data and improve the situation on the ground. As seen in chapter 6, the direct competition with commercial hunters for natural resources, in combination with the exclusion or the access restriction on certain areas of the forest due to conservation efforts, leads to cases of malnutrition and increases mortality rates amongst forest communities (Ohenjo et al., 2006; West et al., 2006). This was problematic for indigenous communities, not only due to over-hunting, but also due to reprisals made against locals by government-run '*eco-guards*', supposedly responsible for controlling poachers but often looking for easier targets (Lewis, 2012b; Caramel, 2017; Corry, 2017; Osborne, 2017; Survival International, 2017).

In terms of this research, the main purpose of this case study was to draft an initial list of requirements for a data collection platform that would use decision trees to enable participants to collect data. As discussed in chapter 6, this case study acted as a proof of concept and it produced a list of requirements that was used in the subsequent case studies. Finally, this case study offered the opportunity for an initial evaluation of decision trees and it demonstrated that the selected hardware and software worked as expected.

In terms of research question RQ 1, this case study was evaluated via a proxy (research assistant) and by analysing his reports, it seemed that the participants were trained quickly and grasped the concept of the decision tree and of pictorial icons representing observations. However, there was a minor indication, from the log analysis, that participants did not favour the navigation button (back button) as the one presented in figure 6.4b. Prior to the field trip, it was hypothesised, that since the participants were just introduced to the UI, they would use the back button in many more occasions to explore the affordances of the UI and find the icons that they were looking for in the decision tree. This low interaction number on the back button could be explained in two different ways; either the participants were extremely confident in their decisions or it could indicate a minor navigation issue in regards to categories. However, since exact performance rates were not present, it was impossible to favour one of the two theories. As a result, the first field trip revealed the need for the author to join the field trips. The fact that the device logs presented a slightly different picture from the observations and reports of the research assistant, indicated that more structured usability evaluations had to take place.

In terms of research question RQ 2, the challenges identified were the difficulty of finding and establishing collaborations with local partners that would include the opportunities for research and the difficulty for researchers to visit the research area in short notice. The former was mitigated by delivering an integrated solution that would work under the local conditions and could potentially lead to further collaborations and research opportunities, while the latter was tackled by gathering an initial list of requirements by interviewing local experts and conducting remote evaluations via a proxy (research assistant).

10.1.2 Case study 2: Participatory monitoring of logging

The second case study was presented in chapter 7 and endeavoured to collaborate with local NGOs in the Republic of the Congo and develop a system for communities to report the socio-economic impacts of logging in their lives. Until then, local communities had seen little benefit from the blooming resource extraction industry that was active in their localities. They have had little say in how the logging concessions were managed, and had no recourse if loggers destroyed resources on which they depended. Thus, with the use of ICT tools and similarly to the earlier logging-related projects, locals would be able to give direct feedback on the behaviour of logging companies, and allow them to accurately map important resources they wanted to claim and protect from destruction.

In terms of this research, the goal of this case study was to extend the previous list of requirements by using more sources (e.g. more anthropologists, NGO representatives, field evaluation), develop a new ICT platform that would tackle local technological challenges and offer pictorial decision trees for data collection and finally evaluate the new prototype in field via participants' observations and structured usability evaluations.

In terms of research question RQ 1, this case study discovered both minor usability issues, that were resolved in-situ, and more essential usability issues when participants were introduced to pictorial decision trees. More specifically, the major usability issues that were identified were the difficulty for participants to comprehend categorical icons and their difficulty in navigating abstract hierarchical structures. Categorical icons were interpreted literally by participants, which caused confusion to many of them, while others seemed to have problems with navigating through the interface and using forward and backward steps. These results were aligned with relevant literature in HCI4D that suggested that the level of education is correlated to other cognitive tasks such as the conceptual abstraction and categorisation (see chapter 4).

In terms of research question RQ 2, this case study revealed that eliciting requirements via a proxy, who has a good contextual understanding, is a valid method with many advantages. It also showed that cognitive walkthoughs and evaluations via a proxy should be used with caution as they failed to identify the major usability issues that were revealed during the field evaluation. This case study also revealed numerous social and cultural challenges when designing and executing structured evaluations 'in the wild' context of the rainforest. Finally, it was demonstrated that 'hypothetical scenarios' do not work well with non-literate participants and alternative methods should be sought for conducting evaluations in this context.

10.1.3 Case study 3: Participatory monitoring of logging

The third and final case study was presented in chapter 8 and endeavoured to collaborate with the logging company CIB in the Republic of the Congo and offer them a version of Sapelli that would allow local communities to map their resources in order to be excluded from future cutting sessions.

In terms of this research, the goal of this case study was to tackle the usability and interaction challenges that were identified in the previous case study. Therefore, this case study sought to evaluate decision trees complimented with audio feedback and physical interfaces as a novel way to interact with ICT systems.

In terms of research question RQ 1, this case study further proved that understanding pictorial decision trees is correlated with the literacy level of participants. It also revealed that audio feedback makes no particular difference in the participants' performance, but it significantly improves their satisfaction and proved to be the preferred method in comparison to plain pictorial decision trees. Finally, this case study showed that physical interfaces lead to higher levels of confidence and better performance, as they enhance the overall user experience. However, both interaction modes come with a number of logistical issues such as recording audio prompts in the local language or designing and printing physical cards to be used in physical interfaces.

In terms of research question RQ 2, in this field study an alternative method of evaluating participants was applied. To avoid bystanders that assisted or confused participants and to avoid hypothetical scenarios that confused participants, the evaluation was conducted during a walk in the nearby forest, where real and practical tasks were executed (e.g. mapping certain trees). These practical, real-life scenarios proved to be more appropriate for the given context. Finally, this case study further validated that a mixture of ethnographic approaches and observations, are more appropriate for the given context.

10.2 Conclusions

This thesis contributes to the rich literature of ICT4D and HCI4D, by exploring whether pictorial decision trees are appropriate as an interaction mode for non-literate participants to capture and share their TEK. In addition, this thesis contributes by providing a methodological approach for evaluating ICT tools among remote communities and stakeholders. This thesis has presented research work with marginalised groups, such as indigenous forest communities in the Republic of the Congo, and it has demonstrated that following an interdisciplinary approach, and adapting methods from UCD, **it is feasible** to enable participants to use scientifically acceptable methods to collect local environmental data and participate in decision-making processes.

As noted, the main focus of this thesis was the usability evaluation and improvement of the tools that could positively impact the sustainability of the approach. As a result, this thesis provides methods for conducting evaluation studies '*in the wild*'. Through three case studies, it has presented the key elements of a methodological approach for introducing and evaluating the technology against local communities, who have often received little or no formal education or exposure to technology. As a result, it has provided an in-depth look at the methodology for conducting usability evaluations outside of the controlled and 'safe' environment of the lab, that resulted in an accuracy improvement of the tools from 75% to over 95%. Thus, it provides project design and engagement guidelines for similar, challenging environments.

Finally, the novelty of the work described in the present thesis lies in the conception, development and testing of the interaction modes for data collection, which permit an entire community, regardless of skills or literacy levels, to create maps of essential features of their local environment for use in logging consultations and improve collaboration and communication. In terms of user interaction, this research is proposing three different interfaces to enable local people to participate in data collection schemes and monitoring activities. It suggests pictorial decision trees as an effective method for semi-literate participants, without and with audio feedback for enhancing the user experience. Finally, it proposes physical interfaces for users with minimal or no formal education for building their confidence and performance.

Although the methodologies and the tools presented here are still work in progress, they could provide a concrete base for long-term engagement and successful development outcomes. Apart from the Republic of the Congo, the same methodologies are used with communities in the Brazilian Amazon to develop land management tools, while in Namibia these ICT tools will be used by Ju ‘hoansi communities to monitor and report illegal invasions of their lands by cattle ranchers. Last but not least, ExCiteS is collaborating with the NGO ClientEarth to provide them with a Sapelli version to be used in Ghana, Gabon and the Republic of the Congo to empower CSOs to take part in processes of law reform and implementation.

10.3 Future work

This thesis acts as a demonstrator in regard to the feasibility of the vision that was set up in chapters 1 and 2. However, there is still a considerable amount of future work to be done in both the technological aspect and the methodological approach.

10.3.1 Data collection

With regards to the technological aspects, there is a lot of work required to further improve the Sapelli platform and make it more robust, intuitive and usable in terms of data collection.

Sapelli designer It was demonstrated that pictorial decision trees are a fast and effective method for navigating between a number of options, but while in the field, they also require a plethora of changes based on the community’s feedback until they reach a satisfactory level. Until now, though, this has largely required the contribution and availability of the technical team to code the decision trees in the required *Sapelli XML*. Researchers working with the communities, who may not be familiar with the necessary technology, would develop the pictures in collaboration with the community for the decision trees, but would then have to send them to the Sapelli developers, who would have to encode them into the required XML structures to construct the decision tree. Afterwards, the necessary files would then be sent back to researchers in the field who would then load them into the app for deployment. Any changes to the decision tree or pictures would necessitate the repetition of this process, which may be extremely difficult, or not possible, should there be inadequate network connectivity for communicating with the developers. This has been a major obstacle in using Sapelli and has hindered wider deployment opportunities.

A Sapelli Designer app (or apps – maybe an online and an offline version) is envisaged as a way of overcoming this challenge. Through a web and/or mobile app, that would be available online, as well as offline, non-expert users would be able to load their own pictures, move them around, and connect them as a way of creating the pictorial decision tree themselves. Once developed, a Sapelli designer could also streamline the process of loading the constructed decision tree into the Sapelli app and allow for immediate deployment. This will lead to increased proliferation and uptake of Sapelli, especially by NGOs, conservation organisations, logging companies, and other interested parties, and therefore open up opportunities to build on the research that was carried out in this thesis.

Tap&Map As described in chapter 8, in the third case study, Tap&Map was conceptualised as a novel system to capture data via physical, tangible interfaces. During the field trip, due to lack of resources just a basic, rudimentary prototype was developed, which was later tested among 32 participants with great success (see section 8.4). Although the prototype was not properly functional, the participants showed an impressive accuracy rate of 97.50%. The follow-up interviews were again very promising since all of the participants found Tap&Map more user friendly, easier to understand and more comfortable to operate compared to Sapelli. Finally, the tangible nature of the cards and the minimal interaction with the unfamiliar smartphone, made the mapping exercise less intimidating for many community members.

A future development goal would be to move from the paper-prototype to a fully functional ICT tool which holds many technical and research challenges to properly implement. The resulting tool could be a stand-alone application, but it could also be integrated with Sapelli to offer a rich data collection experience, where some parts of the data collection process could require textual input, or input via a decision tree and the rest could follow the Tap&Map approach. Also, integrating with Sapelli, Tap&Map can capitalise on Sapelli's flexible transmission system (via SMS messages, Http etc.) and on the authoring tools for project creation, and management as described above. The final outcome would be a flexible and generic stack of software, for communities and NGOs, that could be used across projects but which can be easily reconfigured depending on the demands.

In addition, a collection of cards is easier to be misplaced or lost when compared to a single smartphone that Sapelli requires. This again necessitates communities to be highly motivated and engaged with the project and take care of the equipment and the cards. Finally, it would be interesting as a future direction to investigate different physical methods to collect and keep the cards together, organised and safe, which are at the same time usable and convenient for participants.

The importance of this vision, including Sapelli and Tap&Map, is reflected by the fact that UCL Business awarded me with a '*PhD Enterprise Scholarships*' to explore the commercial potential of the research. Appendix A includes the business plan delivered and approved by UCL Business in January 2016.

Open research questions and challenges Although this research answered all the questions set up at the beginning of the PhD, more questions were born in the lifetime of the projects that still need investigation. For example, it was showed that pictorial decision trees work well under certain circumstances, but there is still room to explore how the number of icons per screen and the tree depth impacts participant's understanding of the structure and how that influences their ability to operate Sapelli.

Another open challenge is a method to transmit media attachments from the field to a central database. While Sapelli includes an SMS transmission mechanism, this can only be used for textual information. Due to the large filesize of the media attachments, the SMS transmission would not be feasible. Sapelli also supports media uploading via Http, but one of the problems that were observed during the field trip was the sparse and slow mobile Internet that was, in most of the cases, insufficient to upload high quality photos. A possible solution would be to generate and use thumbnails of the photos and send the appropriate file depending on the quality and speed of the network. These thumbnails could be used by project managers to better understand the situation in the field. However, the system should be versatile and managers be able to request any given photo in better quality. For instance, imagine a project where participants monitor poaching activities in the area (as in chapter 6) and as part of their observations they take photos of the forest, of dead animals or of traces of poachers. Thumbnails of those photos could end up at the local manager's office, who while examining them, could identify evidence that might lead to a poacher, but because of the low resolution of the pictures the evidence is not clear. In this case, the manager should be able to send a request to the particular device that holds the original photo and request a higher resolution image. This functionality should be orchestrated without any interaction by the end user who is operating the device.

General improvements The use of open-source technologies gave the advantage of working with a very popular and well-maintained operating system, such as Android. However, it also introduced issues as Android matured and new features were introduced to the platform, or old ones were deprecated. As an illustration, the deprecation of the option to put the device in '*flight mode*' within app to preserve battery without the user's consent requires further research on how to design interfaces for non-literate participants to provide the necessary consent on such screens.

Open-source community As new features are introduced to the Sapelli platform, there is the hope to establish an open-source community around the project, with active developers who would offer the resources to discover and resolve issues. An active community will also reassure stakeholders regarding the future stability of the platform and improve the uptake of Sapelli.

10.3.2 Ethical considerations

TEK and Indigenous Knowledge is sensitive information, and its digitisation within the proposed system can lead to risk of unwarranted access or use. Thus, it is necessary to ensure that the intellectual and property rights of indigenous groups are not misused. The work with non-literate users adds to the challenge, as standard protection (e.g. through typed complex passwords) is not applicable here. During this research, we have already experimented with graphic based passwords and data encryption mechanisms. During the experimentation and evaluation of the platform, only test data has been collected and pose no risk to the communities and their intellectual property. However, in the future it is essential to continue considering protection mechanisms and secure storage of information to ensure that the information is treated appropriately, according to the communities' wishes.

Any further sharing of information should follow the FPIC agreement with participating communities and should be shared on secure (password protected) platforms such as ArcGIS Online or GeoKey (see appendix I.2). In a live deployment scenario, data should be backed up and encrypted in the field. In addition, intermediaries that would be interested in working with us will have to sign data agreements, which will follow the agreement decided in the FPIC process. Data that will be defined by the community, intermediaries, or the research team as potentially sensitive, should be shared only with trusted partners after signing the relevant agreement.

10.3.3 Moving beyond data collection

With the data collection and transmission elements of the Sapelli platform advancing, the next ambitious challenge is to develop geographical analysis and visualisation tools that can be used, successfully, by local communities in culturally appropriate ways. The concept coined by ExCiteS, is called '*Intelligent Maps*' and it constitutes a novel approach to visualisation, analysis and editing of spatio-temporal data, in ways intelligible to non-literate or technically and map illiterate users.

The intention is to develop a (tablet) application which tackles the map literacy issue from two complementary angles. On the one hand, this solution could lower the bar by providing a simple interface and on the other hand it could increase the participants' abilities through training. The aim is to design a novel graphical user interface, entirely devoid of textual and numeric elements. Bringing basic GIS functionality within reach of non-literate users requires a thorough rethinking of the interaction of these systems. The promising results of physical interfaces could be applied to tackle this challenge and physical interfaces could be possibly integrated with tutorials and/or include elements of play.

The importance of this vision was also shared by the European Research Council (ERC), since the ExCiteS group has secured €2.5m from the ERC to continue the research endeavour towards '*Intelligent Maps*'. The funding will allow the group to build on the development of Sapelli and Tap&Map in the coming 5 years and further contribute to the fields of ICT, HCI, geography, geographic information science, anthropology, development, agronomy and conservation.

10.4 Closing remarks

Once again, it is stressed that the contributions that this work presented in the disciplines of ICT, ICT4D, HCI and HCI4D, in combination with the ICT tools presented in the thesis, achieved the research questions that were set up at the start of this PhD journey. Additionally, as presented in this chapter, this work constitutes a concrete basis for further exciting research that contributes towards tackling one of the most challenging development goals of our century, the sustainable management of resources in national and international levels.

A Commercial Evaluation

This chapter explores the commercial potential of the research conducted in this thesis, and it is structured in the format of a business plan. This chapter provides space for investigating and evaluating the commercial potential of this thesis.

Syllego: data collection solutions

Michalis Vitos

February 2016

A.1 Executive Summary

A.1.1 Business Summary

Syllego is a start-up organisation whose vision is to create and provide software solutions for NGOs and indigenous communities to monitor, analyse and act on environmental trends, regardless of the community's literacy or technical ability. The name *Syllego* comes from the Greek word συλλέγω meaning to collect or gather information, and depicts the company's focus on offering data collection services. All around the world, local indigenous communities possess unique, complex and adaptive systems of knowledge that have enabled them to manage their environments sustainably, sometimes for thousands of years[1]. This knowledge is termed Traditional Ecological Knowledge (TEK), and is increasingly being recognised by environmental managers as critical for sustaining the environment[2].

The software solutions provided by Syllego, are primarily based on the open-source platform named Sapelli[3]. Sapelli is a new mobile data collection and sharing platform designed with a particular focus on non-literate and illiterate users with little or no prior ICT experience. Sapelli has been co-designed and co-developed by the founder of Syllego during the process of his Ph.D. research.

A.1.2 The Market

Syllego has identified two major segments that will be interested in the provided software solutions to assist stakeholders in providing sustainability for indigenous land management. By enabling local communities to participate in efficient and scientific data collection, this start-up aims to lower the costs of in-situ monitoring, especially in remote locations, where current practices rely on expensive '*expeditions*' by scientists which are not sustainable in terms of costs, time and effort, and longevity of observations. These segments are the most likely consumers of our developed technologies. The sectors are as follows:

1. Extractive industries and their global supply chains (Timber, Oil/Gas, Fish stocks, and Transport corridors) could use the software solutions of Syllego, to improve their social and environmental credentials, while also reducing the costs of, and adding credibility to, their monitoring activities by enabling

[1] Huntington, Henry P. (2011). "Arctic science: The local perspective". In: *Nature* 478.7368, pp. 182–183. DOI: 10.1038/478182a.
[2] Berkes, Fikret (2012). *Sacred Ecology*. L: Routledge. ISBN: 041551732X.
[3] http://www.sapelli.org

local communities to act as monitors of violations of licensing and also avoid situations where accreditation to export to the EU is under threat.

2. The Syllego services can be directly linked to the regulatory frameworks such as the EU FLEGT and the European Environment Agency (EEA)'s regulations by providing services and tools to stakeholders - indigenous groups, extracting companies (logging, mining), CSOs, accreditation organisations, governments, Small and medium-sized enterprises (SMEs), NGOs and other companies - to monitor the changes that are happening in the environment, understand them, and adapt to these changes.

A.1.3 Business aims

Syllego's vision is to develop tools and provide services for high quality data collection in challenging scenarios that enable better environmental management and empower local communities to take action. Syllego aims to establish itself, as the pioneer company on data collection in remote and extreme environments. Some of the business aims for the first three years of operations include:

- Increase sales by double in the first three years.
- Expand the Syllego's team with the addition of two software developers and a project manager in the first three years.
- Extend current software solutions and develop new pioneer tools that enable communities anywhere, regardless of location and literacy level, to contribute in data collection campaigns.

A.1.4 Financial summary

The total start-up requirements for establishing the company comes to £15,500.00, which is partially covered by the direct investment of the owner by £10,000.00 and financing of the rest £5,500.00. According to the estimated financial planning, presented in detail in appendix A.8, Syllego will break-even in the 8th month of operations. During the first years of operations, the business will have a revenue of £85,000.00, resulting in net profits of £7,140.00, which is 8% ratio of net profits/-sales. In the second year, it is estimated that the ratio will increase to 12%, while in the third year, it will increase to 15%.

A.2 Elevator Pitch

Community monitoring for carbon credits has been demonstrated by the Surui carbon credits through the use of technology to provide evidence[4]. By enabling local communities to participate in efficient and scientific data collection, Syllego aims to lower the costs of in-situ monitoring, especially in remote locations, where current practices rely on expensive '*expeditions*'. The environmental industry sector that focuses on reducing environmental degradation and preserving ecosystem services, has flourished in terms of revenues since the 2008 financial crisis. Companies like FSC have shown turnovers of over 20,000,000 EUR, and create clear opportunities for companies like Syllego to offer services on the data collection by local communities to reduce costs and increase the accuracy of the collected information.

Syllego will offer software solutions for relevant stakeholders and indigenous communities to monitor, analyse and act on environmental trends, regardless of the community's literacy or technical ability. Syllego will offer high-quality software solutions at competitive prices that will benefit these stakeholders in the extractive industries, as well as in their supply chains. The solutions offered will allow the involvement of local communities in directly taking part in data collection, monitoring and verification of licensing. This will have a huge social and environmental impact, as it will reduce the cost, it will add value and credibility to the extraction companies and it will promote the sustainability of local communities and the environment.

A.3 Company Summary

Syllego is a start-up organisation that will be founded as a London-based limited share company. The company will be owned by its founder Michalis Vitos.

A.3.1 Company Ownership & Owner's Background

The company will be founded and owned by Michalis Vitos. Michalis is a respected entrepreneur currently pursuing and finishing a Ph.D. in software engineering and data collection. Prior to joining the ExCiteS research group in 2012 and pursuing his Ph.D., Michalis has worked for more than three years as an independent Web Developer, SEO and IT consultant with a focus on designing, developing and deploying high-quality digital products. He is the founder of iDesigner[5] (set up in 2011), a web development company based in Thessaloniki, Greece. iDesigner has

[4]Rainforest Alliance (2016). *The Suruí Forest Carbon Project*. URL: http://www.rainforest-alliance.org/business/climate/validation-verification/projects/surui-project (Accessed on 1st Feb. 2016).
[5]http://www.idesigner.gr

undertaken the design and development of more than 10 high quality projects and mobile applications.

In 2011, Michalis co-founded QRshop[6], an innovative sales platform based in Greece that enables customers to order products with the use of their mobile phone or tablet, from wherever they are with the use of QR codes. In 2011, he also founded CasualArt[7], an e-shop based in Greece that focused on selling canvas images and art objects throughout Greece.

Michalis will leverage his extensive knowledge and industry contacts to make Syllego a success. As an entrepreneur and CEO of his own business, is used to being in charge and responsible for the market analysis, developing the business plan, formulating a strategy, dealing with the fierce competition and adapting to the market demands and requirements. Some of the most important lessons and skills that he picked up in the last 5 years are the ability of identifying the right opportunities and entering into business, the ability of identifying capital sources/funding and applying, the skill of collaborating with others and delegating duties, but most importantly the skill of self-managing his time, setting up his own schedule and working independently but also keeping a professional attitude towards clients and collaborators. Most of those skills were extremely valuable in his current effort to complete a Ph.D.

You can find the full CV of Michalis on pages 238 to 240.

A.3.2 Start-up Summary

The total start-up requirements for establishing the company, including legal costs for trademark registration and licence discussions with UCL, branding, accounting etc., comes to £15,500.00 (table A.1). These start-up requirements are to be financed partially by the direct owner investment of £10,000 and financing in the amount of £5,500.00, as shown in table A.1.

A.3.3 Company Locations and Facilities

Initially, Syllego will be operated out of the owner's home in London in order to save on rent. A small office in the home dedicated to Syllego's activities will be sufficient, since at the start-up the company will be composed only of the owner and the services offered do not require a separate work space.

[6]http://www.qrshop.eu
[7]http://www.casualart.gr

Table A.1.: Start-up requirements summary

Start-up expenses	
Legal	£ 1,000.00
Company registration/setup	£ 400.00
Accounting	£ 500.00
Hardware/software	£ 2000.00
Logo design	£ 300.00
Domain Hosting	£ 100.00
Business development	£ 3,000.00
Stationery	£ 200.00
Total start-up expenses	**£ 7,500.00**
Start-up assets	
Cash required	£ 8,000.00
Other Current Assets	-
Long-term Assets	-
Total start-up assets	**£ 8,000.00**
Total Requirements	**£ 15,500.00**

As the company grows in the coming years, and the personnel expands after recruiting talented programmers and project managers, the company's base of operations will be moved to rented office spaces such as the WeWork, at South Bank, London[8]. WeWork provides flexible month-to-month office facilities, with all the necessary amenities for the company's start-up. Using office services as WeWork, which provide a work environment at a reasonable rate, will assist Syllego to keep expenses low.

A.4 Services

Syllego will offer software solutions for NGOs and through intermediaries to indigenous communities to monitor, analyse and act on environmental trends, regardless of the community's literacy or technical ability. All around the world, local indigenous communities possess unique, complex and adaptive systems of knowledge that have enabled them to manage their environments sustainably, sometimes for thousands of years[9]. This knowledge is termed Traditional Ecological Knowledge (TEK), and is increasingly being recognised by environmental managers as critical for sustaining the environment[10].

The software solutions that will be provided initially by Syllego, will be primarily based on the open-source platform named Sapelli[11]. After a year's Research and Development (R&D), Syllego will also offer a solution named Tap&Map.

A.4.1 Sapelli

Sapelli is a new mobile data collection and sharing platform designed with a particular focus on non-literate and illiterate users with little or no prior ICT experience. Sapelli has been co-designed and co-developed by the founder of Syllego during the process of his Ph.D. research.

The Sapelli platform currently consists of 3 main components: the *Sapelli Collector:* a data collection app, with integrated data sending service for Android devices; the *Sapelli Relay:* an Android app designed to receive and forward SMS messages; and the *Sapelli Server:* a web server application to receive and store data. Figure A.1 shows the overall architecture of the platform.

[8] https://www.wework.com/locations/london/south-bank

[9] Huntington, Henry P. (2011). "Arctic science: The local perspective". In: *Nature* 478.7368, pp. 182–183. DOI: 10.1038/478182a.

[10] Berkes, Fikret (2012). *Sacred Ecology*. L: Routledge. ISBN: 041551732X.

[11] http://www.sapelli.org

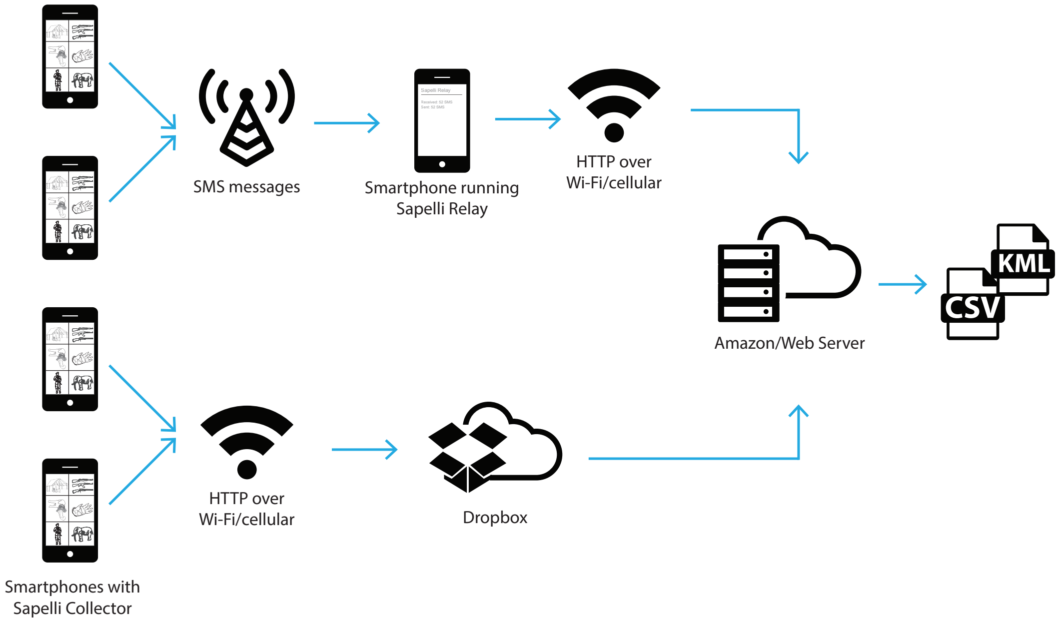


Figure A.1.: Sapelli Architecture.

Sapelli runs on Android phones and tablets, and is designed to be generic. The platform is intended to enable communities with varying needs and abilities to engage in mobile data collection – often, but not necessarily, across language or literacy barriers – in a wide variety of scenarios and contexts. A typical Sapelli survey takes the form of a *pictorial decision tree*. The tree represents a question with a predefined set of answers organised in a hierarchical structure. The leaves represent the most specific answers or classifications, while the in-between nodes represent categories or groups that lead to these final answers. Users navigate the decision space by repeatedly 'tapping' images to select child nodes until they reach a leaf node (figure A.2). Sapelli supports multiple decision trees in sequence and thus it can collect answers for multiple questions. Due to the focus on low and non-literate users, it is as straightforward as possible to build pictorial decision trees and icon-driven interfaces as in figure A.2. Also, all of the records can be augmented with photos, audio recordings and location with GPS coordinates through accessible and intuitive user interfaces.

In terms of Intellectual Property (IP), Sapelli is open-source and it is distributed under the Apache 2 licence[12], which allows third parties to commercially use and adapt the software as long as the required notices are included.

In order for Sapelli to be generic enough and to be used in other contexts, projects were intentionally separated from the actual mobile data collection application. The Sapelli Collector can be equated with a web browser, a software for retrieving, parsing and presenting information available on the World Wide Web (WWW).

[12] http://www.apache.org/licenses/LICENSE-2.0

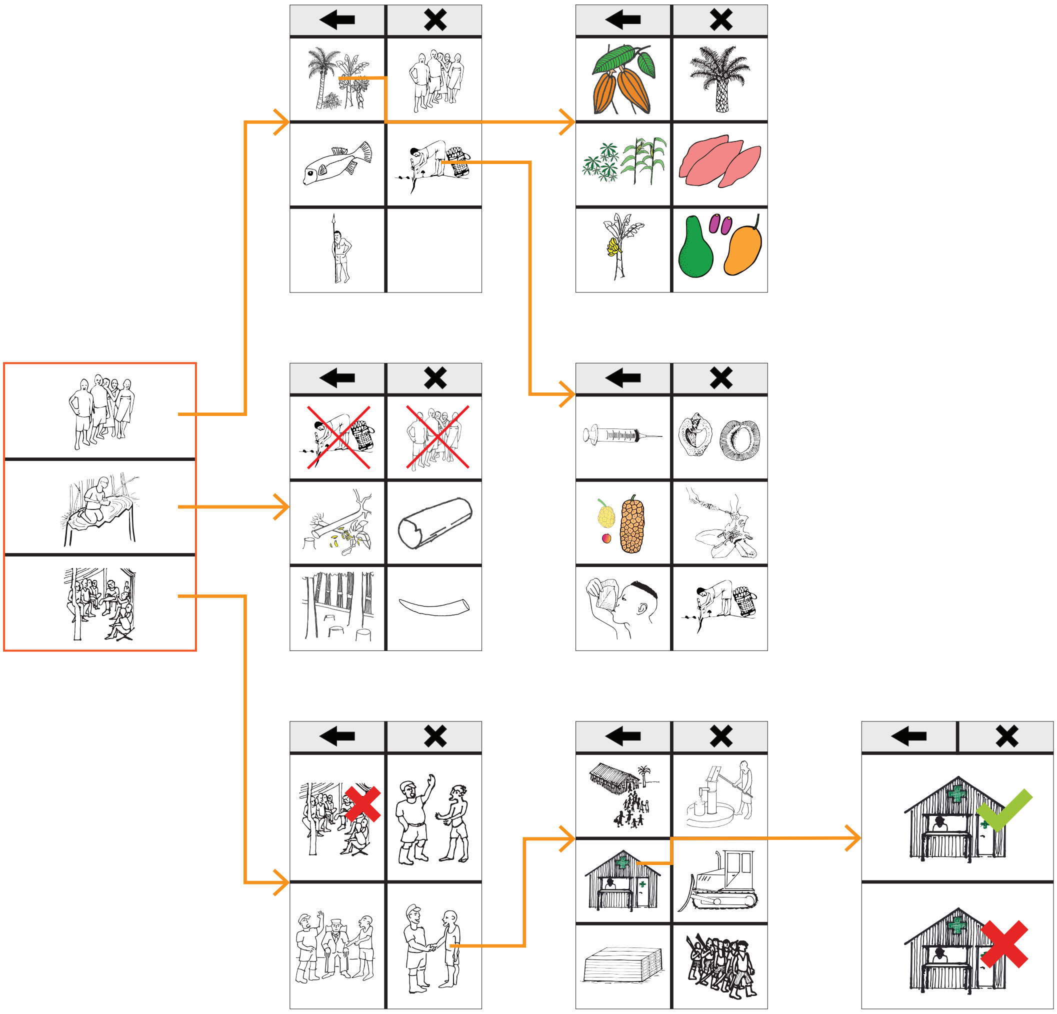


Figure A.2.: Part of a Sapelli decision tree developed with international NGO Forests Monitors. *Forests Monitor (2013)*. Monitoring App for Android. URL: *http://www.forestsmonitor.org/fr/capacity_building_congo_ii/572554 (Accessed on 10th Aug. 2015)*.

Similarly, the Sapelli Collector can retrieve, parse and present information from a Sapelli project file containing surveys described in a bespoke XML language.

Although Sapelli was designed as a generic and abstract platform that communities could embrace to create their own projects, there is still a market potential for Syllego to offer integrated solutions for data collection campaigns, from conceptualisation to project design and to field data collection. Syllego has the know-how to design and adapt complex XML projects, and modify the Sapelli core to serve the unique requirements of specific clients.

Some of the services that Syllego can offer on the data collection process include:

1. Advice, or hands-on assistance, on the design and implementation of complex data collection forms and decision trees that could be used for data collection

in challenging environments where participants have limited or no experience with modern, digital technology.
2. Adaptation of the data collection tools to meet the unique requirements of each project. For instance, during the development of Sapelli, ExCiteS collaborated with the international NGO FPP[13], to expand the UIs of Sapelli with textual forms that were harmoniously integrated, with clear boundaries and possibly access restrictions between the pictorial UIs. This was useful in cases where users with different abilities or roles needed to use the same device. For instance, NGO representatives could set up monitoring sessions using a textual form, after which the same device could be passed on to non-literate community members to collect data associated with that session. Similarly, each project presents unique challenges that require code modifications into the Sapelli core.
3. Assistance on the selection of appropriate hardware depending on the project needs, especially hardware that will properly operate in challenging environments like remote and rural areas etc.
4. Offer training on NGOs on how to use the data collection software and how to integrate the software with their current workflow.
5. Offer integration of Sapelli with the client's GIS, or Information Technology (IT) systems, to increase productivity, improve operations, centralise data storage and increase performance.
6. Generate reports and analyse the collected data, in order to produce meaningful reports or to extract needed insights.

A.4.2 Tap&Map

Even though pictorial interfaces reduce the accessibility barriers that text introduces, still they do not provide a universal solution. This is because many users, especially those who have never had any formal education or who are completely unfamiliar with digital technology, face difficulties using mobile applications. After conducting research in the field, the owner of Syllego conceptualised a radical prototype with a focus on eliminating categorisation and navigational structures and reducing the interaction with the device that significantly improves participants' efficiency. The prototype consists of two elements, (a) a series of cards, each with an icon representing a site to be mapped; and (b) a smartphone application. Each card would be equipped with a NFC tag and would then act as a tangible user interface. The application would react when one of the 'control' cards is touched on the device. When, for example, a participant wants to record a point of interest, such as a banana tree, he or she: (a) selects the appropriate card from a stack of cards (figure A.3b);

[13] http://www.forestpeoples.org/

(b) touches the card to the phone while standing as close as possible to the site to be mapped (figure A.3c). The device then reads the user's location from the GPS sensor and stores it along with other necessary metadata (such as the selected card, device id, time, etc.). We call this concept *Tap&Map* and hypothesised that in comparison to on-screen decision trees, it could enable a simpler and more intuitive way for non-literate participants to map local resources (or collect other kinds of information depending on the project scope).

(a) Printed prototype cards. **(b)** Picking the appropriate card. **(c)** Mapping a medicinal tree.

Figure A.3.: Prototype version of Tap&Map.

During field trips in Republic of Congo, a rudimentary prototype of Tap&Map was tested with great success. Although the prototype was not fully functional in reality and no real data were collected, the participants showed an impressive accuracy rate of 97.50%. The follow-up interviews were very promising as well, since all of the participants found Tap&Map more user friendly, easier to understand and more comfortable to operate compared to Sapelli. Finally, the tangible nature of the cards and the minimal interaction with the unfamiliar smartphone, made the mapping exercise less intimidating for many community members.

At Syllego we aim to further work on the concept of Tap&Map, in the first year of operation, and create a fully functional application. The resulting tool will be a stand-alone application, but since Sapelli is open-source, it will also be integrated with Sapelli to offer a rich data collection experience, where some parts of the data collection process might require textual input, or input via a decision tree and the rest follow the Tap&Map approach. Also, integrating with Sapelli, Tap&Map can capitalise on Sapelli's flexible transmission system (via SMS, Http etc.) and on the authoring tools for project creation, and management. The final outcome will be a flexible and generic stack of software, for communities and NGOs, that can be used across projects but which can be easily reconfigured depending on the demands.

Similarly, Syllego visions to offer consultancy, adaptation and support services to NGOs, private companies, SMEs etc. that would be interested in using Tap&Map, Sapelli or a combination of both for completing data collection campaigns in challenging and hard to access environments.

A.5 The Market

Community monitoring for carbon credits have been demonstrated by the Surui carbon credits through the use of technology to provide evidence[14]. Moreover, as the recent EU state of the environment report noted, '*For example, the environment industry sector, which produces goods and services that reduce environmental degradation and maintain natural resources, grew by more than 50% in size between 2000 and 2011. It has been one of the few economic sectors to have flourished in terms of revenues, trade and jobs since the 2008 financial crisis.*' Indeed, in the area of accreditation the FSC is our best example. FSC over the last 20 years has grown to an organisation with a turnover of over 20,000,000 EUR and providing jobs locally to many other organisations.

With significant funding being committed to the UN Green Climate Fund approaching 9 billion EUR, REDD+[15] development, and the increased commitments of developed countries to dedicate 0.7% of GDP to aid, over the next 20 years there are plenty of opportunities to private sector SMEs and social-economy SMEs to contribute to growth in jobs and innovations. For instance, in the REDD decisions, it is stated that all the countries participating in United Nations Framework Convention on Climate Change (UNFCCC) have to establish National Forest Monitoring Systems (NFMS) for monitoring, reporting and verifying the status of REDD activities (Decision 2/CP.15[16]), creating clear opportunities for companies like Syllego to offer services on the data collection by local communities to assist the role of NFMS.

A.5.1 Market Segmentation

Syllego has identified two major segments that will be interested in the provided software solutions to assist stakeholders in providing sustainability for indigenous

[14] Rainforest Alliance (2016). *The Suruí Forest Carbon Project*. URL: http://www.rainforest-alliance.org/business/climate/validation-verification/projects/surui-project (Accessed on 1st Feb. 2016).

[15] REDD is an effort to create a financial value for the carbon stored in forests, offering incentives for developing countries to reduce emissions from forested lands and invest in low-carbon paths to sustainable development.

[16] UNFCCC. Conference of the Parties (COP) (2010). *Report of the Conference of the Parties on its fifteenth session, held in Copenhagen from 7 to 19 December 2009. Addendum. Part Two: Action taken by the Conference of the Parties at its fifteenth session.* UNFCCC. URL: http://unfccc.int/documentation/documents/advanced_search/items/6911.php?priref=600005735.

land management. By enabling local communities to participate into efficient and scientific data collection, this start-up aims to lower the costs of in-situ monitoring, especially in remote locations, where current practices rely on expensive '*expeditions*' by scientists which are not sustainable in terms of costs, time and effort, and longevity of observations. These segments are the most likely consumers of our developed technologies. The sectors are as follows:

1. Extractive industries and their global supply chains (Timber, Oil/Gas, Fish stocks, and Transport corridors) could use the software solutions of Syllego, to improve their social and environmental credentials, while also reducing the costs of, and adding credibility to, their monitoring activities by enabling local communities to act as monitors of violations of licensing and also avoid situations where accreditation to export to the EU is under threat.
2. The Syllego services can be directly linked to the regulatory frameworks such as the EU FLEGT and the EEA's regulations by providing services and tools to stakeholders - indigenous groups, extracting companies (logging, mining), CSOs, accreditation organisations, governments, SMEs, NGOs and other companies - to monitor the changes that are happening in the environment, understand them, and adapt to these changes.

For instance, in the case of logging, companies that are pursuing the FSC certification are faced with direct and indirect costs[17]. The direct costs are related to the fees payable to the certification body and depend on the size of the certified area and the ease of assessment[17]. The indirect costs, though, are related to the necessary upgrades in the company's management and monitoring efforts and heavily depend on the size of the area and the management and monitoring mechanisms already in place to meet the sustainable requirements set by the certification body[17]. Reports, estimate that the cost ranges from $0.10/acre up to more than $1.00/acre per year[17]. For example, CIB is one of the largest forestry companies in the RoC and ExCiteS has collaborated with them during the Sapelli development to run a pilot case study in the area, and explore the feasibility of the approach. CIB operates in an area of 3.2 million acres, which translates in costs that range from $320K up to $3.2M per year. The solutions that Syllego offers, aim to significantly reduce the associated costs for managing, monitoring and verifying the sustainability requirements set by the certification body to a fraction of that cost.

[17] Gupta, H. S., M. Yadav, D. K. Sharma and A. M. Singh (2013). *Ensuring Sustainability in Forestry: certification of forests*. The Energy and R. ISBN: 8179934950.

A.5.2 Competitor Analysis

In the context of humanitarian aid, development or conservation projects in the LICs, mobile data collection platforms running on PDAs or smartphones are more suitable and popular since they offer more efficient and convenient data collection with fewer errors compared to the traditional paper forms.

As a result, nowadays, there are a myriad of mobile data collection platforms available on the digital market covering a broad range of needs and requirements. From the available solutions, we identified ten key providers which stand out for their maturity and popularity, and act as a competitor to our services:

- CyberTracker
- EpiCollect
- FrontlineSMS
- imogene
- KoBo
- Magpi
- ODK
- OpenXdata
- Poimapper
- RapidSMS

We have reviewed these providers in terms of project management, form features, synchronisation, sensor capabilities, costs and finally data visualisation and analysis capabilities. These criteria are relevant to projects dealing with development, environmental justice, conservation efforts, etc.

Management refers to the simplicity of the platform and the tools it offers to managers to create and maintain projects. For example, EpiCollect provides an easy web interface for configuration, while CyberTracker requires a special installation of a desktop tool. Features refers to form elements each platform supports such as text, numeric, date and location, and depending on the platform, a form can also support different features such as sub-forms, mandatory questions, data range and validation, and skip patterns. Synchronisation refers to the methods for transferring the collected information to a central database and distributing the projects from a manager's office to the mobile devices in the field. For example, ODK supports both synchronisations via Internet, while CyberTracker requires a computer connection for extracting the data and updating the project. Sensor capabilities refer to the various embedded sensors of mobile devices, such as an accelerometer, digital compass, gyroscope, GPS, microphone, and camera that each of the platforms supports. Finally, the cost refers to whether a platform is open source and free to use such as EpiCollect, ODK etc., while the data visualisation and analysis criterion refers to the tools that these platforms offer for representing and analysing the collected information.

Although there are so many platforms on the market, almost all of them offer similar functionalities, covering the requirements of analogous use cases. Their purpose is often to digitise existing paper-based forms, facilitate the data collection procedure by eliminating errors, applying data constraints and validation, and standardise the process. As a result, these applications are generally targeting literate user populations with at least basic computer operational skills, or in areas with easy access to infrastructures such as power and Internet.

However, to cover the needs of NGOs, SMEs and other stakeholders in the extraction industries and global supply chains, there is a need for data collection tools that pay attention to the User Interface (UI) design and allow low or non-literate users, with non-existing computer skills to collect and distribute information. Some of the features that differentiate Syllego's solutions, from the others available in the market, include:

1. Text free, pictorial based interfaces and interaction mechanisms that enable a wide range of participants to collect, analyse and share local information.
2. Support of flexible and automated data sync that can operate in remote and rural environments where typical mobile and Internet infrastructure is absent.

A.6 Strategy and Implementation

Syllego has the potential to define the target market and differentiate itself by offering a unique solution to the industry today. Syllego's sales and marketing strategy will be a combination of mass marketing techniques to targeted NGOs, SMEs and private organisation, as well as a focused direct sales endeavour.

A.6.1 Strategy Pyramid

Our main strategy is the growth of customers that will provide the necessary revenues for self-sustaining the business and investing on the R&D of the offered solutions.

The methods employed to grow the customer base are:

1. Increasing market awareness by meeting key stakeholders and demonstrating them the advantages of using Syllego's solutions for their business.
2. Providing high-quality and consistent services to customers.
3. Offering good value and sustainable solutions to our customer in terms of costs, time and effort.
4. Offering the under-development prototypes in promotional prices to clients, in order to advertise the solutions and fund the funding of R&D.

A.6.2 Value Proposition

Syllego will offer high-quality software solutions at competitive prices that will benefit stakeholders in the extractive industries and in their supply chains. Currently social and environmental credentials are conducted by '*experts*' or '*scientists*' during the course of expensive and time-consuming expeditions. The solutions offered by Syllego will allow stakeholders to involve local communities directly in the process of data collection, monitoring and verification of licensing. This will have a huge social and environmental impact, as it will reduce the cost, it will add value and credibility to the extraction companies and will promote the sustainability of local communities and the environment.

A.6.3 Competitive Edge

Our competitive edge is our innovative software solutions, our extensive knowledge of the area where our customers operate, and our long-term commitment to customer satisfaction. The software offered as a service by Syllego, has been developed over 4 years at UCL, as part of the ExCiteS research group that aims to give indigenous communities the means to monitor, analyse and act on environmental trends, regardless of their literacy or technical ability.

As part of the ExCiteS group, the owner of Syllego has conducted innovative research with a focus on the conceptualization and design of new, intuitive UIs for data collection, validation and dissemination by non-literate users, taking into account the cultural differences of the users, and the evaluation of tools by organising and conducting usability studies and evaluations in various contexts. The UIs and prototypes that will be offered by Syllego have been developed and evaluated with a diverse and broad audience, to ensure that the resulting technologies incorporated in the software platform do not discriminate on the basis of sex, gender, age, income, social status, literacy, technological familiarity.

A.6.4 Marketing Strategy

The first strategic step for Syllego will be to design and develop a website that will reflect the corporate identity and credibility of the business. The website will showcase all the available services that Syllego offers, along with the provided software tools and various case studies that show how the tools have been already used in various contexts. The first month will be allocated for that purpose. An important addition to add creditability to the website, will be written testimonials from customers who have used Sapelli in the past, and can comment on the advantages of using ICT for the purpose of data collection.

Next, the focus will be on public relations and networking which is paramount to the success of Syllego. The company is aiming at a very narrow, and specific, target group; thus, traditional marketing strategies as advertising, postal or email campaigns will not be much effective in raising awareness of the company. On the contrary, networking activities and direct sales endeavour will be attempted instead.

During the first year, Syllego will conduct the following public relations activities:

- Reach contacts in NGOs and SMEs that have already used Sapelli during the research phase and arrange meetings for demonstrating the new features of the software and discuss potential interest in further collaborations.
- Utilise links that the owner's supervisors at UCL have to expand and build up network.
- Arrange face to face meetings with these links and discuss potential collaborations or agreements for future joint bids.
- Participate, either as a presenter or attendee, in industry and academic conferences, as well as events organised by international NGOs, which are dedicated to environmental monitoring, climate change, TEK etc. These venues will provide an opportunity to further build up the company's network.
- Join networks and communities where potential clients attend and expand the business network. Networks such as the Royal Institute of International Affairs[18], commonly known as Chatham House, facilitate interesting debates on international affairs and policies, and key stakeholders that could be benefited from our technologies can be identified in their events.
- Reach out to SMEs linked to the EU FLEGT regulation and offer them demonstrations of Syllego's solutions. In addition, offer them collaborations either in

[18] https://www.chathamhouse.org/

terms of using our services, either in terms of jointly applying for funding to provide common solutions.

An amount of £2,000.00 has been allocated for the purpose of participating in conferences and events, and having in person meetings with links in our network.

A.6.5 Pricing Strategy

Syllego's pricing strategy will be to enter the market by offering services that will enhance the data collection procedures and reduce the cost that companies already invest in capturing this information. Each client will be a unique project with different requirements and needs to the others, thus the price for the provided services will heavily range depending on the requirements and time necessary to complete the project. However, it is estimated that a single data collection project that requires a month's effort on Syllego's time will be priced at £7,000.00.

A.6.6 Sales Strategy

Syllego is targeting indigenous groups through intermediaries, extracting companies (logging, mining), CSOs, accreditation organisations, governments, SMEs, NGOs and other companies that require methods to monitor the changes that are happening in the environment. Syllego will capitalise on the existing links and connections that have been established during the Ph.D. research of the company's owner, and during the research development of Sapelli. Face to face meetings will be arranged with NGOs that have already trialled Sapelli in pilot projects and efforts will be made to establish new collaborations. The next step of the sales strategy will include contacting decision makers and other relevant stakeholders, and introducing them to Syllego's solutions and their products by arranging meetings. Then throughout the year, there are many industry and academic conferences, as well as events organised by international NGOs that are dedicated to environmental monitoring, climate change, TEK etc. Syllego will use these venues as an opportunity to expand the potential client list and pitch the provided solutions to interested parties.

Sales Forecast

Table A.2 illustrates the estimated sales for the first year. We are assuming that capitalising on the previous and new links, Syllego will establish collaboration with 6 clients and will sale them services of designing and adapting decision trees, adapting the Sapelli software & integrating it with their current IT infrastructure, providing training and finally generating reports. Table A.3 shows a sales forecast for the first 3 years of operations, including direct cost associated with the sales. Finally, figure A.4 and figure A.5 present sales forecasts in a monthly basis as well as yearly projections. Forecasts have been conservatively estimated to increase the likelihood of attainment, and have been calculated with the assumption that new projects arise bimonthly to ensure that previous projects have been delivered successfully. Finally, the sales have been broken down by customer group, including the most prominent customers for our business.

Table A.2.: Sales Forecast by services.

Services	Qty	Price	Amount
Adapting decision trees	4	£4,000.00	£16,000.00
Adapting Sapelli	2	£10,000.00	£20,000.00
Integrating Sapelli with IT system	2	£9,000.00	£18,000.00
Training sessions	6	£2,500.00	£15,000.00
Generate reports & analyse data	4	£4,000.00	£16,000.00
		Total	**£85,000.00**

Table A.3.: Sales Forecast by customer group.

Sales Forecast	Year 1	Year 2	Year 3
NGOs	£28,333.33	£55,250.00	£103,416.67
SMEs	£28,333.33	£55,250.00	£103,416.67
Governments	£28,333.33	£55,250.00	£103,416.67
Total Sales	**£85,000.00**	**£165,750.00**	**£310,250.00**
Direct Cost of Sales	**Year 1**	**Year 2**	**Year 3**
NGOs	£3,258.33	£6,353.75	£11,892.92
SMEs	£3,258.33	£6,353.75	£11,892.92
Governments	£3,258.33	£6,353.75	£11,892.92
Total Costs	**£9,775.00**	**£19,061.25**	**£35,678.75**

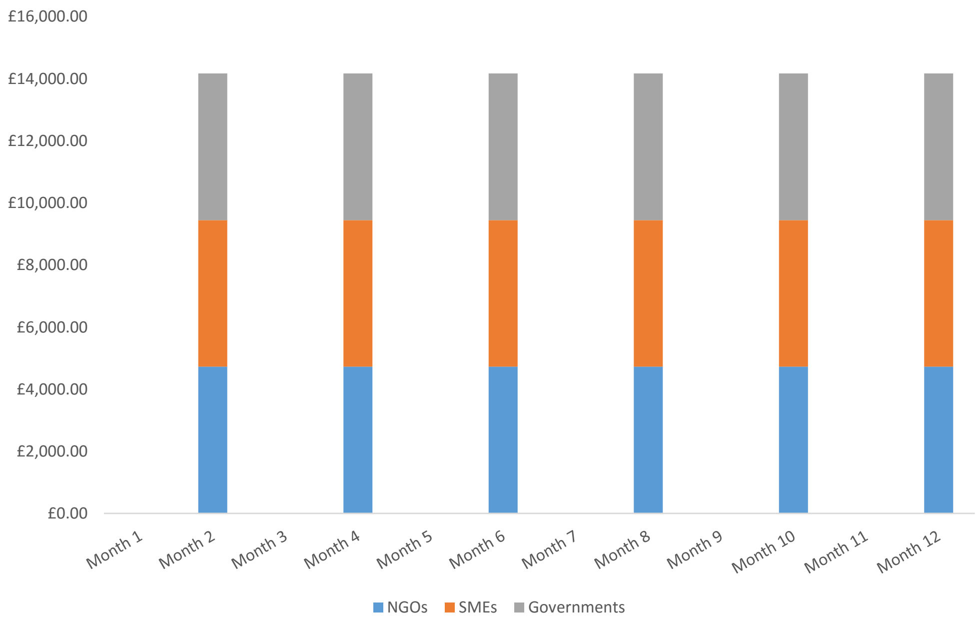


Figure A.4.: Monthly sales.

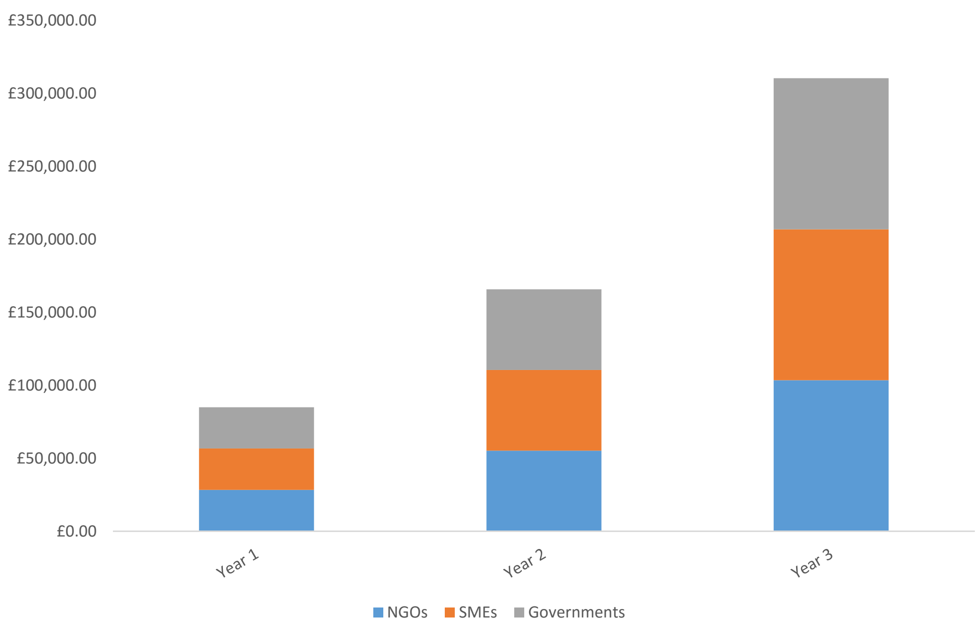


Figure A.5.: Annual sales.

A.7 Management Summary

Syllego is a start-up organisation that will be founded as a London-based Ltd company. The company will be owned by its founder Michalis Vitos.

A.7.1 Personnel Plan

Syllego will grow its personnel in the coming three years, depending on how accurately and efficiently the company is able to implement the goals of this business plan. After the first year, and given that new projects arise, Syllego will hire a mobile developer to further develop the provided software solutions. Then at the third year, an experienced back-end developer will be hired to assist in the providing more integrated solutions and a project manager to support in clients' retention (table A.4).

Table A.4.: Personnel Plan

	Year 1	**Year 2**	**Year 3**
Owner	£55,000.00	£57,750.00	£60,637.50
Mobile Developer	-	£45,000.00	£47,250.00
Back-end developer	-	-	£45,000.00
Project Manager	-	-	£40,000.00
Total	**£55,000.00**	**£102,750.00**	**£192,887.50**

A.8 Financial Plan

The following section presents the financial plan for Syllego.

A.8.1 Break-even analysis

Figure A.6 illustrates the break-even analysis for the first year of operations. We assume running costs to include payroll, direct costs for providing services and an estimation of other running costs as presented in table A.1 and in table A.5. According to these assumptions, Syllego breaks-even after the 8th month of operations.

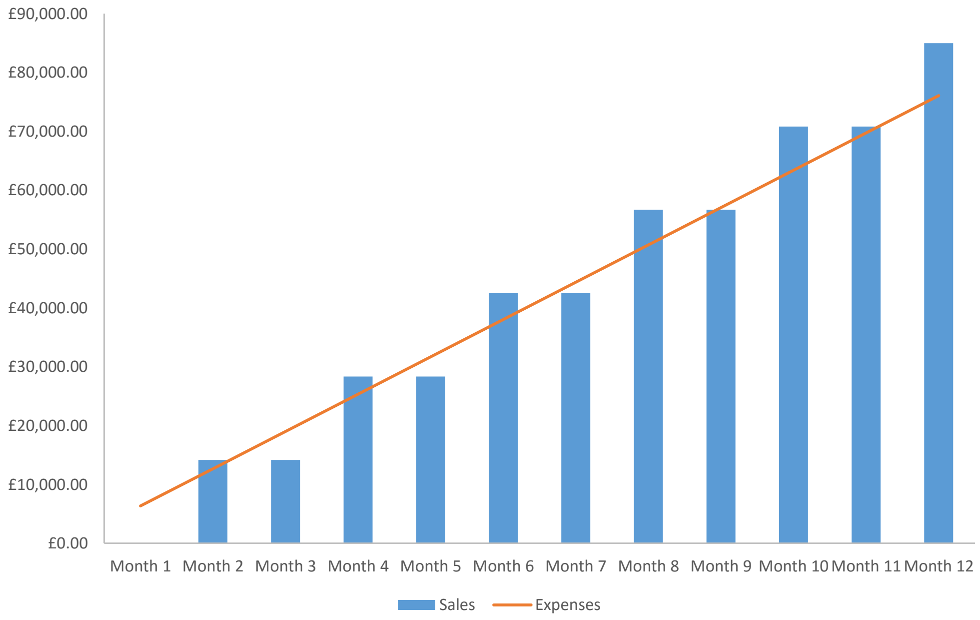


Figure A.6.: Break-even Analysis.

A.8.2 Projected Profit and Loss

Figure A.7 illustrates a 3-year projected profit and loss diagram, while table A.5 shows in detail the estimated profits and loss during the first three operational years of the business. This financial planning depends on important assumptions, such as:

- The assumption that the economy will show a slow growth during the next three years, without any major recessions.
- The assumption that access to investment will be secured to fulfil the business goals described in this plan.
- The assumption that there will be no unforeseen advances in technology to make our products and services obsolete.

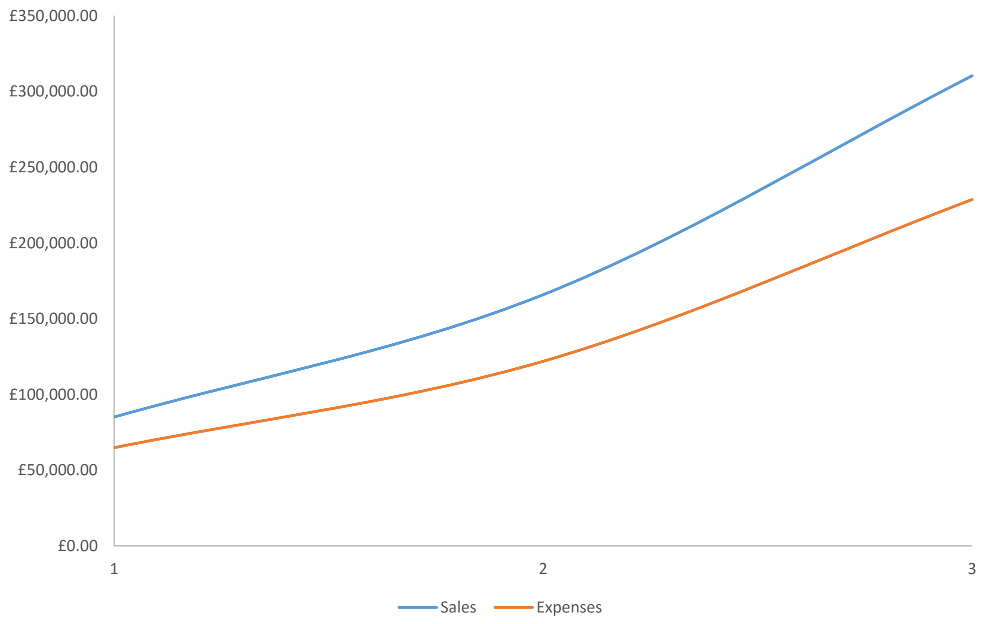


Figure A.7.: Projected Profit and Loss.

Table A.5.: Pro Forma Profit and Loss

	Year 1	Year 2	Year 3
Sales	£85,000.00	£165,750.00	£310,250.00
Direct cost of Sales	£9,775.00	£19,061.25	£35,678.75
Payroll	£55,000.00	£102,750.00	£192,887.50
Legal	£6,000.00	£10,000.00	£14,000.00
Rent	-	£4,500.00	£4,725.00
Accounting	£500.00	£525.00	£551.25
Hardware/software	£1,500.00	£1,575.00	£1,653.75
Web design	£1,000.00	£1,050.00	£1,102.50
Domain Hosting	£100.00	£105.00	£110.25
Advertisement/brochures	£2,000.00	£2,100.00	£2,205.00
Stationery	£200.00	£210.00	£220.50
Profit Before Interest and Taxes	**£8,925.00**	**£23,873.75**	**£57,115.50**
Taxes	£1,785.00	£4,774.75	£11,423.10
Net Profit	**£7,140.00**	**£19,099.00**	**£45,692.40**
Net Profit/Sales	8%	12%	15%

Appendix I: CV

Michalis Vitos

address: 58A Ufford Street, SE1 8QB, London, UK
mobile: +447577144675
email: michalis.vitos.11@ucl.ac.uk or info@michalisvitos.gr

I am currently a Ph.D. student at UCL and part of the research group ExCiteS (Extreme Citizen Science) which brings together scholars from diverse fields to develop and contribute to the guiding theories and methodologies that will enable any community to start a Citizen Science project and will help them deal with issues concerning them.

My overall research objective is to develop innovative ICT and GIS tools that can be used by semi-nomadic and non-literate indigenous communities to monitor environmental changes and resource extraction in scientifically validated ways. Enabling communities to better understand these changes can lead to more informed decision-making.

Education

2012-...

UCL (University College London), London, United Kingdom

- Ph.D. Candidate
- Topic: Data collection and Geographic visualisation for non-literate citizen scientists
- My research interests include amongst others data collection and visualisation techniques, Human-Computer Interaction (HCI), HCI4D, ICT4D, Citizen Science, GIS, Participatory GIS, Web and Mobile Development, Software Engineering.

2008-2010

University of Macedonia, Thessaloniki, Greece

- MSc in Applied Informatics
- Applied Informatics degree with special emphasis on the development of systems for managerial and economic applications and the training of high level executives.
- Master Thesis: Visualisation of the geographical location of a website’s visitors in real time and statistical display.

2007-2008

Cisco College

- Cisco Certified Network Associate, CCNA
- CCNA certification validates the ability to install, configure, operate, and troubleshoot medium-size routed and switched networks, including implementation and verification of connections to remote sites in a WAN.

2003-2008

Higher Technological Educational Institution of Thessaloniki, Greece

- Bachelor's degree in Information Technology Engineering
- Computer Science and Computer Engineering degree where emphasis is given to the general principles of computers and to the organization, operation and architecture of computational systems and networks.
- Bachelor Thesis: I/O Benchmarking.

Employment Highlights

2011-...

Founder / Owner / Director
iDesigner, http://www.iDesigner.gr

- iDesigner is a web development company based in Thessaloniki, Greece.
- Main purpose in iDesigner is the creation and development of high quality web applications and web sites.
- Developed more than 10 websites and 3 Android web applications generating a revenue of more than 20K EUR.

2011-… (Dormant since 2012)

Co-Founder / Co-Owner / Co-Director
QRshop, http://www.QRshop.eu

- QRshop was an innovative sales platform that enabled customers to order products with the use of their mobile phone or tablet, from wherever they are with the use of QR codes.

2011-… (Dormant since 2012)

Founder / Owner / Director
CasualArt, http://www.casualart.gr

- CasualArt was an e-shop based in Greece, selling canvas images and art objects throughout Greece.
- CasualArt was the first online canvas shop in Greece, offering the option to upload and customise a photo before ordering.

2009-2011

IT Manager - Application Developer
Kourasanit, http://www.ecokourasanit.gr

- Developed and maintained the company's website and blog.
- Develop and maintained applications for internal use, such as Client system for storing and retrieving company's clients and Report system keeping daily reports from the corporate staff.

Awards/Funding

Funds that I am part of, or awards that I have been awarded in the past years:

- ‘Extreme’ Citizen Science – ExCiteS grant, funded by the Engineering and Physical Sciences Research Council (EPSRC reference EP/I025278/1).
- “Participatory monitoring for forest management and measure the social impact of logging in Republic of Congo” funded by NGO Forest Monitor.
- “Participatory monitoring for forest management in DRC and Cameroon” funded by NGO Forest Peoples Programme.
- ESA App Developer Camp awarded by European Space Agency (ESA)
- ESA Space App Camp awarded by European Space Agency (ESA)
- Research Methods in Human-Computer Interaction summer school awarded by Tallinn University, Estonia
- ARCMap - Accessible, Reachable Community awarded by CEGE Small Grants funds
- CS2015 Travel Award awarded by Citizen Science 2015 conference

Publications

- Stevens, M and Vitos, M and Lewis, J and Haklay, M (2013) Participatory monitoring of poaching in Congo basin. In: (Proceedings) GIS Research UK (GISRUK) 2013
- Vitos, M and Stevens, M and Lewis, J and Haklay, M (2013) Making local knowledge matter: Supporting non-literate people to monitor poaching in Congo. In: (Proceedings) Third Annual Symposium on Computing for Development (ACM DEV 2013)
- Vitos, M and Stevens, M and Lewis, J and Haklay, M (2013) Community Mapping by non-literate Citizen Scientists in the Rainforest. In: Bulletin of the Society of Cartographers, 46 (1-2) 3 - 11

Posters

- Gliozzo, G., Vitos, M., & Stevens, M. (2012). From education to action: How technology enables public participation in the context of environmental conservation. Presented at: Conference on Public Participation in Scientific Research (PPSR2012). Portland USA.
- Stevens M, Vitos M, Altenbuchner J, Conquest G, Lewis J, Haklay M. Introducing Sapelli: A mobile data collection platform for non-literate users. Presented at: Fourth annual Symposium on Computing for Development (ACM DEV-4). 06 Dec 2013
- Mastracci D, Vitos M, Stevens M, Altenbuchner J, Lewis J, Haklay M, Robbins P. How can ICT assist socio-ecological resilience in the Arctic?. Presented at: ICTD 2013. 09 Dec 2013

B

Case study 1: Participatory monitoring of poaching: Technical work

B.1 Requirements

Table B.1.: Functional requirements for Anti-Poaching tool

Req. #	Priority	Description	Rationale
General			
FR-G-1	High	The system shall enable forest community participants to collect evidence and information on poaching activity.	—
FR-G-2	High	The system shall operate on mobile, handheld devices.	Since the system should allow observations in the forest, the devices should be compact and light for participants to carry. Thus, laptops or desktop computers are not applicable because of (a) size, bulkiness; (b) power requirements and (c) lack of sensors such as GPS.

Req. #	Priority	Description	Rationale
FR-G-3	High	The system shall be free for interested communities and open source.	The use of affordable equipment and open source technologies would allow the easier adoption of the technology by communities and stakeholders, since the software would be free to use, distribute and modify. This is important for national and international NGOs that operate on limited resources. Open source technologies would also allow the adaption of the tools developed in other, different contexts by interested communities or stakeholders.
FR-G-4	High	The system shall complement each observation with geographical coordinates from a GPS receiver.	Observations complimented with GPS coordinates could provide reliable evidence for poaching activities.
FR-G-5	High	The system shall enable users to complement observations with an audio recording, photo or video.	Audio, photos and videos could provide additional information and evidence.
FR-G-6	High	The system shall enable transmission of the collected observations to a centralised database.	Syncing of collected information to a central database and providing access to relevant stakeholders would enable better monitoring of poaching activities.
FR-G-7	Medium	The system shall enable easy modification of the icons (In accordance with FR-U-1 and FR-U-2).	Data collection projects are work in progress and the icons might change due to participants' lack of understanding etc. or shift in requirements.
FR-G-8	Medium	The system shall enable easy modification of the decision tree and the structure (In accordance with FR-U-1 and FR-U-2).	—"—

Req. #	Priority	Description	Rationale
FR-G-9	Medium	The system shall allow visualisation of the observations.	The collected data should be visualised in order for relevant stakeholders to take action upon the data. For instance, the observations could be visualised on a map.
Usability			
FR-U-1	High	The system shall support decision tree structures.	Pictorial decision trees showed promising results in similar scenarios to enable non-literate participants to collect geo-referenced points (Lewis and Nelson, 2006; Lewis, 2012b; Lewis and Nkuintchua, 2012).
FR-U-2	High	The system shall support UIs with only pictorial structures, devoid of any textual or numerical information.	Multiple researchers have shown that non-literacy is a major obstacle in using mobile devices and interfaces, as virtually any standard UI contains textual and numerical elements (Chipchase, 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2009; Chaudry et al., 2012; Kodagoda et al., 2012) (see section 3.2).
FR-U-3	High	The system shall include navigation buttons to move between the different screens of the decision tree.	Previous research supports the use of back buttons for non-literate users to navigate on pictorial decision trees (Lewis and Nelson, 2006; Lewis, 2012b; Lewis and Nkuintchua, 2012).
FR-U-4	High	The system shall operate in full-screen mode and hide from the user the device's status bar that displays information such as time, battery level, signal strength.	This information could confuse or distract a user.

Req. #	Priority	Description	Rationale
FR-U-5	High	The system shall operate in loop mode where after making an observation, the user shall be presented with the home screen of the decision tree.	This would allow users to make multiple observations and prevent them from being presented with screens that include textual information such as settings screens or the system *home* screen.
FR-U-6	High	The system shall inform the user that an observation has been made and stored internally.	This complies with the HCI principles introduced by Nielsen (1993) (see section 4.2).
Security			
FR-S-1	High	The system shall be protected and accessible only to allowed users.	Access should be restricted since users collect points of interest that are valuable and sensitive for their local community.
FR-S-2	High	The system shall allow users to make observations from a safe distance.	In projects where security is an issue, for instance when users record the location of a poacher's camp, recoding from a safe distance is paramount to not risk participants' personal safety.
Hardware			
FR-H-1	High	The devices shall be robust, waterproof and dustproof.	The devices should be robust enough to endure the adverse rainforest conditions, and the rough treatment that we expected our participants to have on the devices.
FR-H-2	High	The devices shall be equipped with GPS receivers.	In accordance with FR-G-4.

Req. #	Priority	Description	Rationale
FR-H-3	High	The devices shall be equipped with a touch screen.	Touchscreens would enable users to interact directly with the icons displayed on the screen rather than choosing and selecting them though a keyboard or stylus which could cause confusion and difficulties to participants. In addition, even in cases of semi-literate participants, physical keyboards on devices are primarily designed for English input and finding devices with a keyboard mapping to the local language could be challenging (Parikh and Lazowska, 2006).
FR-H-4	High	The devices shall be equipped with a camera.	In accordance with FR-G-5.
FR-H-5	High	The devices shall be equipped with gyroscope and compass sensors.	According to FR-S-2, the users should be allowed to make observations from a safe distance. Recording the orientation of the device could allow to meet this requirement; thus, gyroscope and compass sensors on the device are necessary.
FR-H-6	High	The devices shall have a battery autonomy of one week.	—
FR-H-7	High	The system shall be accompanied by a charging solution appropriate for the local conditions.	Given the lack of electricity in the case study area (see section 3.2), an appropriate charging solution should be provided to ensure the feasibility of the system.
FR-H-8	Medium	The devices shall have removable batteries.	In cases where the devices run out of energy, spare batteries could be provided to participants and enable them to continue recoding observations.

B.2 Hardware Evaluation

Initially, the top priority was to find fit-for-purpose devices and charging solutions to be used for the ICT prototype that cover the *Hardware* requirements as listed in table B.1, as the hardware would dictate the development environment and the available software. The devices had to be robust enough to endure the adverse rainforest conditions, and the rough treatment that we expected our participants to have on the devices (FR-H-1). In addition, they should be affordable and equipped with decent GPS capabilities (FR-H-2).

(a) Trimble Juno SC

(b) Samsung Xcover

Figure B.1.: PDA device compared to Android smartphone. *Juno SC © Trimble; Xcover © Samsung*

Since it was required for the devices to be portable, lightweight and mobile (FR-G-2), different options were examined. In terms of mobile devices, in 2012, there were feature phones[1], smartphones and PDA devices. Feature phones were immediately abandoned, due to lack of processing power, built-in sensors and Software Development Kits (SDKs) for developing apps for them. Next, different PDA devices (i.e. Trimble Juno SC as in figure B.1a, Trimble Juno 3D) and smartphones (i.e. iPhone, Android, and BlackBerry) were evaluated. In order to find the most appropriate

[1]Feature phones are low-end mobile devices that have limited capabilities compared to smartphones and are typically used only for voice calls and text messages.

and cost-effective solution, at ExCiteS we organised a workshop during *The 2nd Citizen Cyberscience Summit*, that took place in Feb 2012, in London. The purpose of the workshop was to have a discussion with a quite diverse crowd – researchers, practitioners, NGOs such as *The Global Canopy Programme* (GCP, 2015), that were involved in citizen science initiatives and had valuable insights into equipment.

The PDAs were abandoned due to cost[2], bulkiness and unintuitive stylus-centric screens (table B.2). Finally, Android seemed to be the most appropriate environment, due to the open source character and the versatility (FR-G-3). The open source nature of Android meant that the OS could be deployed on many different hardware platforms allowing the options of cheaper hardware. Also, the lack of cost to license the OS in turn reduced the cost of the phones. In comparison with rival platforms, most notably Apple's iOS, Android devices come in a much wider variety and price range (some costing less than £60). In terms of development, both platforms offered easy to access SDKs, but in terms of distributing the app, Android operated an open app market, while Apple gated the Apple Store and reviewed all the apps before publication (Butler, 2011). Regarding security, in Android applications run on their own space and do not have access to the system resources without explicit user permissions. On the contrary, iOS apps can access system resources, thus they have access to private and sensitive information without the user providing the permission (Butler, 2011). Finally, targeting a platform that was used by many different vendors could also prevent vendor lock-in and dependency on a handful of brand-specific, ageing models, which was what happened to early PDA-based platforms like CyberTracker (see section 4.1.2 and appendix C.1.1) or the Helveta system (section 4.1.2).

Table B.2.: Devices comparison.

Device	Cost	Robustness	Processing power	Size	Touchscreen
PDAs	Very expensive	Very robust	Low	Bulky	Stylus
Android	Not expensive	Very robust	High	Lightweight	Yes
Blackberry	Expensive	Fragile	High	Lightweight	Yes
iPhone	Expensive	Fragile	High	Lightweight	Yes

Hence, in order to withstand the harsh rainforest conditions and not-so-gentle treatment by the participants, a rugged, water-resistant, Android smartphone was looked

[2] A typical, rugged PDA device ranged from £1,000 to £3,000, not including the cost for the external GPS sensor. In 2015, and although the prices of these devices have drastically dropped, a *Trimble T41 Rugged* costs £1,240.

for. There was an increasing number of such devices on the market. However, most rugged devices were targeted at military or industrial users and had correspondingly high price tags[3]. Fortunately, at that point some mainstream smartphone vendors had introduced much cheaper rugged devices aimed at the general public to be used in active sport such as off-road running. The device that was chosen was the Samsung Galaxy Xcover, as shown in figure B.1b (Samsung, 2012), an Android-based smartphone that had a durable body, a scratch-resistant Gorilla Glass screen (Corning, 2012), and was IP67-certificated (International Electrotechnical Commission, 2012), which means it was dust tight and waterproof up to 1m.

Figure B.2.: Hatsuden Nabe charging pot © *Jerome Lewis, ExCiteS group*

The other major technological challenge derived from the lack of an electricity grid, to power the high energy-consuming smartphones (FR-H-7). Solar panels were the first candidates to be evaluated. However, after discussions with Lewis, who had an extensive knowledge of the local conditions, it was realised that due to the dense forest canopy there was little direct sun-light that reached the ground level, which made it hard to use solar power to its full potential. Thus, during *The 2nd Citizen Cyberscience Summit's* workshop different power alternatives were discussed, such as *thermoelectric generators* that convert thermal energy into electrical.

[3]For instance, '*Solarin*', a military-grade device is priced at $17,000 (Cooney, 2016).

Finally, it was decided that two solutions for charging the devices, would be trialled during the feasibility evaluation in the coming field trip, to ensure appropriateness to the local conditions. The first was a combination of a rollable solar panel and an external auxiliary battery that stores energy for later use. This could allow electricity to be generated during the day and used to charge devices at night (as the people doing observations will likely be on the move during the day). However, as mentioned above, due to forest canopy there was little direct sunlight that reached the ground level. Thus, another more appropriate method was looked for producing electricity. The best alternative that was found was the Hatsuden Nabe[4] (figure B.2), a Japanese-produced customised cooking pan that converts thermal energy from a fire into electricity that could be used to charge electronic devices while cooking food or boiling water (TES NewEnergy Corp., 2012). This solution seemed ideal for the lifestyle of the communities who had easy supplies of firewood and always kept a fire going to cook food and to keep animals at bay (Lewis, 2012a).

B.3 Software Evaluation

At the start of the project, a key decision was whether to develop the application in the de facto Android programming language, where Java in combination with XML is used, or to develop the application using web technologies (e.g. HTML5 language). HTML5-based applications for smartphones make use of web standards and web languages such as html, XML, CSS, JavaScript and could in theory be deployed in different mobile operating systems (Android, iOS, Windows Mobile Phone).

However, at that point HTML5 applications could not integrate with some of the mobile phone's sensors, also not all HTML5 functionality was supported by the various browsers found on the smartphones (Gibson, 2012). In addition, HTML5 expected, most of the times, always-on Internet connectivity in order to work, or it required the implementation of complex caching strategies (Kinlan, 2011). In contrast with HTML5 apps, native Java applications can have access to swipe and multi-touch events, have access to hard keys events – to disable for example the volume keys on a device, have access to hardware like the camera and GPS and finally have access to some of the operating system functionalities such as enquire the system about the battery status (Mahemoff, 2011).

Next, another important decision had to be made, whether to develop the application from scratch or use an existing data collection platform. Since digital tools can offer more efficient and convenient data collection with fewer errors (Stanton, 1998;

[4] The solution was proposed by Dr Tyng-Rong (Jenny) Roan, a PhD student of ExCiteS at that time, during the 2nd Citizen Cyberscience Summit's workshop.

Pundt, 2002; Lefever et al., 2007; Thriemer et al., 2012), they had already been proved popular in the context of humanitarian aid, development or conservation projects in the LICs. As a result, at that point there were a myriad of mobile data collection platforms available on the digital market covering a broad range of needs and requirements.

As noted in section 6.3, using an existing solution was the preferable option. Hence, a review of already existing mobile platforms that offered data collection services was conducted to decide which one to use as a starting point for an Anti-Poaching prototype. The following section (B.3.1) provides some necessary definitions for data collection *projects* and the different type of *users*, while appendix B.3.2 presents the evaluated platforms, the criteria of evaluation and the results.

B.3.1 Projects and Actors

At this point, and before the evaluated platforms are introduced, it is helpful to define what a data collection project is, identify the type of actors existing in the data collection domain and their responsibilities.

The term **project** is used to describe surveying tasks. In digital data collection, projects consist of **forms** that can be composed of different information type elements such as text, numeric, date and location, and depending on the platform they can have different features such as sub-forms, mandatory questions, data range and validation, and skip patterns.

In terms of users, the first entity is the **developer**, who is responsible for creating, maintaining or updating the software. The developer could be one person, a team or a whole community as seen in open source projects.

The second entity is the **manager** (or **supervisor**), who is responsible for creating and updating projects using the appropriate platform and generating results and reports with the collected information. Managers could be private or public organisations like NGOs or could even be communities who are willing to monitor their local environment by collecting meaningful information.

Finally, the last entity is the **surveyor** (or **user**) who uses the software application and collects information in the field. The surveyor could collect survey data by interviewing people (**respondents**) and filling out in digital forms their responses or he/she could collect personal information and fill the survey by himself as it happens in participatory paradigms where the surveyor and the respondent are the same person (Lewis and Nelson, 2006; Lewis, 2012b; Lewis and Nkuintchua, 2012).

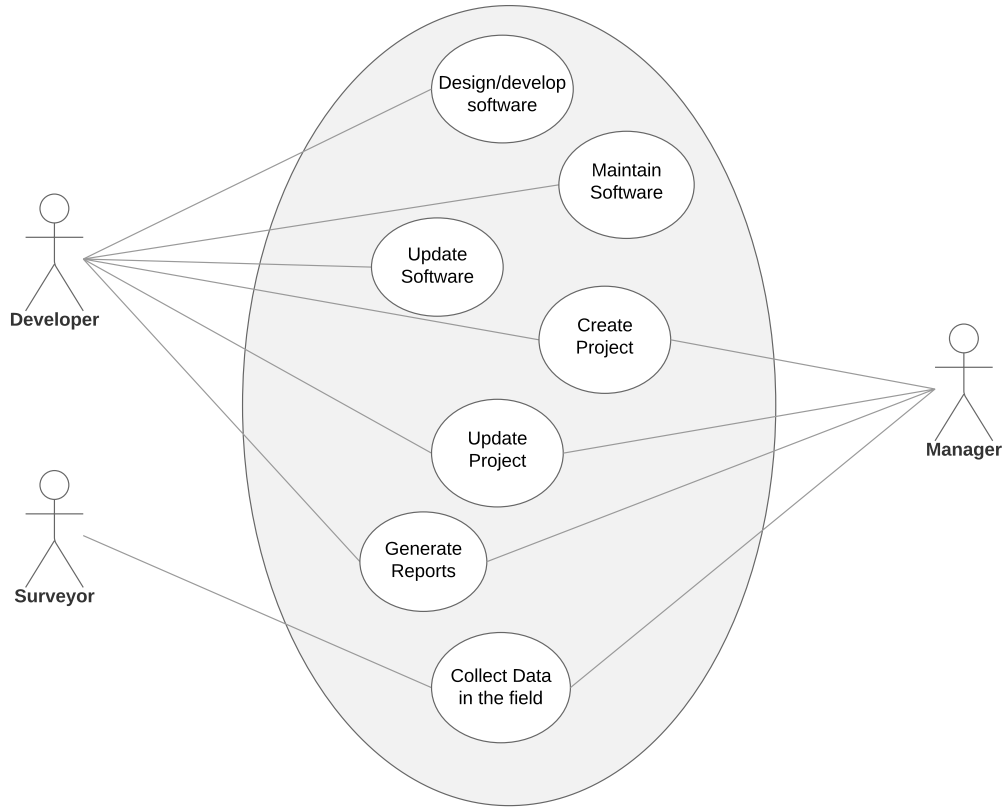


Figure B.3.: Data collection actors.

Figure B.3 shows the users' type and the roles of each of them. However, in some rare cases the roles could change or intersect, for example there could be a case where the developer, the manager and the surveyor could be the same person or organisation that wants to control each aspect of the data collection procedure.

B.3.2 Evaluating the Different Platforms

As of 2012, there were numerous mobile data collection platforms and applications. Project NOMAD, supported by the French NGO CartONG (CartONG, 2013) and iMMAP (IMMAP, 2013), was an attempt to categorise and organise all these collection platforms into one website and provide assistance to humanitarian and development NGOs in selecting the appropriate tools for their needs. At the time, the list of platforms counted 31 providers that promised to offer solutions for mobile data collection (NOMAD, 2013). From that list, ten key providers were identified that stood out because of their *sophistication* and *popularity*. Sophistication is used to describe the functionalities a solution could offer; while popularity was measured by the number of projects using a specific solution provider, the magnitude of the projects relying on that solution and lastly the size of the active community that was supporting and maintaining the software.

The reviewed tools, for which there is a detailed description in appendix C, were:

- CyberTracker (discussed in appendix C.1.1)
- EpiCollect (discussed in appendix C.1.2)
- FrontlineSMS (discussed in appendix C.1.3)
- imogene (discussed in appendix C.1.4)
- KoBo (discussed in appendix C.1.5)
- Magpi (discussed in appendix C.1.6)
- ODK (discussed in appendix C.1.7)
- OpenXdata (discussed in appendix C.1.8)
- Poimapper (discussed in appendix C.1.9)
- RapidSMS (discussed in appendix C.1.10)

The evaluation is presented in detail in appendix C, but in summary, the main criteria in the review were *project management*, *form features*, *synchronisation*, *sensor capabilities*, *cost* and *data visualisation* in order to cover the functional requirements as presented in table B.1.

Management refers to the simplicity of the platform and the tools it offers to managers for creating and maintaining projects (for more details, see appendix C.2.1). This would cover requirements FR-G-7 and FR-G-8. For example, EpiCollect provides an easy web interface for configuration, while CyberTracker requires a special installation of a desktop tool.

Form features refers to the form elements that each platform supports such as text, numeric, date and location, and depending on the platform a form can also support different features such as sub-forms, mandatory questions, data range and validation, and skip patterns (for more details, see appendix C.2.2). Form features could be used to cover the usability requirements such as FR-U-1, FR-U-2, FR-U-4 etc.

Synchronisation refers to the methods for transferring the collected information to a central database and distributing the projects from a manager's office to the mobile devices in the field (for more details, see appendix C.2.3). This was necessary for FR-G-6, FR-G-7 and FR-G-8. For example, ODK supports both synchronisations via Internet, while CyberTracker requires a computer connection for extracting the data and updating the project.

Sensor capabilities refer to the various embedded sensors of mobile devices, such as an accelerometer, digital compass, gyroscope, GPS, microphone, and camera that each of the platforms supports (for more details, see appendix C.2.4). This could cover FR-G-4, FR-G-5 and FR-S-2, as long as the selected devices could cover FR-H-2, FR-H-4 and FR-H-5. Finally, cost and data visualisation (for more details, check sections C.2.5 and C.2.6 respectively) refer to requirements FR-G-3 and FR-G-9.

After evaluating all potential solutions, ODK was identified as the most appropriate solution as a basis for the first Anti-Poaching prototype. The ODK platform is developed as part of an open source project led by the University of Washington (Hartung et al., 2010; Rajput et al., 2012; Open Data Kit, 2015b), is designed to be modular and consists of tools such as ODK Build, Collect (figure C.7), Aggregate, Manage, which cover various aspects of the data collection process. For instance, ODK Build allows users to design form-based surveys, which are described in a format based on the XForms standard (W3C, 2003, 2015). These surveys can then be deployed to Android devices running the ODK Collect application, which facilitates the actual data collection and the uploading of results to a central database. At this central point ODK Aggregate and ODK Manage may be used to visualise, analyse and manage incoming data.

Table B.3 summarises the analysis presented in appendix C. The main reasons for choosing ODK Collect (the Android application of the ODK tools) were the fact that it was an open-source initiative and therefore open to modifications and alterations, it was part of a wider suit of tools (ODK Build, ODK Aggregate, ODK Sensor etc.) that could be useful on a later stage; finally, it had a large support community and a lot of working paradigms for reference. For instance, according to the ODK website, there are more than 100 case studies using ODK as part of their data collection process (Open Data Kit, 2015a).

Table B.3.: Comparison of evaluated platforms.

PROVIDER	IT	Icons	Decision tree	Offline	Trans-mission	Sync	GPS	Photo	Audio	Video	Query	Maps	Graphs	Export
CyberTracker	Low	✔	✔	✖	✖	✔	✔	✔	✔	✔	✔	✔	✔	✔
EpiCollect	Low	✖	✖	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
FrontlineSMS	Moderate	✖	✖	✔	✔	✖	✖	✖	✖	✖	✔	✔	✖	✔
imogene	High	✖	✖	✔	✔	✔	✔	✔	✔	✔	✔	✔	✖	✖
KoBo	Moderate	✖	✖	✔	✔	✖	✔	✔	✔	✔	✔	✔	✔	✔
Magpi	Low	✖	✖	✔	✔	✖	✔	✔	✔	✔	✔	✔	✔	✔
Open Data Kit	High	✔	✔	✔	✔	✖	✔	✔	✔	✔	✔	✔	✔	✔
OpenXdata	High	✖	✖	✔	✔	✖	✔	✔	✔	✔	✔	✖	✖	✔
Poimapper	Low	✖	✖	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔	✔
RapidSMS	High	✖	✖	✔	✔	✖	✖	✖	✖	✖	✔	✖	✖	✔

B.4 Software Development

B.4.1 Security

As mentioned earlier in section 3.2, one of the most challenging problems was that of security and more specifically personal safety. The dramatic or even fatal consequences of Mbendjele's members being caught by poachers, led to investigation and implementation of methods for restricting access to the Anti-Poaching application so that the true purpose of the device could be hidden or denied (FR-S-1). Because the participants were non-literate, conventional authentication mechanisms such as passwords and Personal Identification Numbers (PINs) were not appropriate. Instead, a pattern unlocking mechanism was experimented with. When the application was opened, the user was first presented with a screen consisting of 9 dots, as shown in figure B.4. To get past this screen the user had to draw a previously agreed on pattern, only known to approved participants, by sliding a finger over the dots on the touch-screen, as shown on the right part of figure B.4.

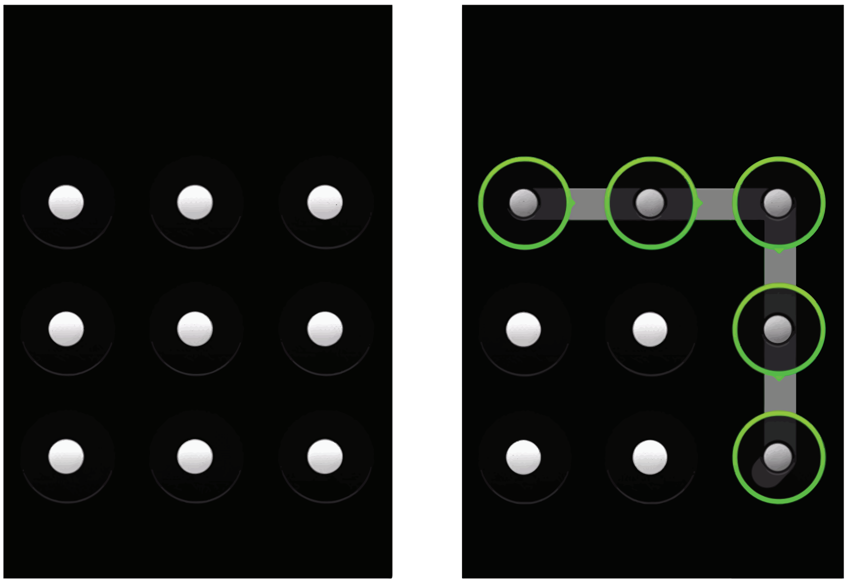


Figure B.4.: Pattern unlocking mechanism.

If the pattern was recognised the user would be presented with the main menu shown in figure 6.4a. Even for literate users this mechanism typically works faster than typing a password or a PIN and the assumption was that non-literate people would be able to learn and remember the patterns. This type of access control is well known to Android users, as it is one of the ways the operating system allows users to unlock their device. However, here it was used to restrict access to an application, rather than to the device itself, meaning that all other, 'unsuspicious' functionalities remain unobstructed.

B.4.2 Approximate Position

Making observations of (possibly) active poachers' camps represents an obvious risk of being spotted or caught. Hence the Mbendjele prefer to stay at a safe distance. In order to still record the position of the camp (or another hard to approach place), an innovative feature was implemented that allowed participants to point the device in the direction of the camp and provide an estimation of the distance that separates them from it (FR-S-2). The combination of the user's own position (obtained through GPS), the orientation (registered using the built-in compass/gyroscope [FR-H-5]), and the estimated distance allowed the computation the approximate position of the camp (see figure B.6).

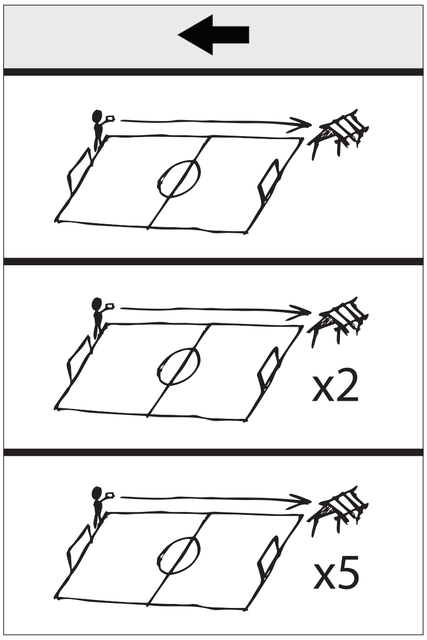


Figure B.5.: User interface for distance estimation.

The question then was how could these participants, who were unfamiliar with standardised distance units and had no or limited numeracy skills, been asked to express distance. The solution that was invented, was to let them express distance as a number of football pitches, a concept they were familiar with from seeing them in logging towns. As illustrated in figure B.5, the UI allowed participants to select a distance of 1, 2 or 5 football pitches. Few Mbendjele can read numbers, however, due to the sensitivity of the project, it was planned to introduce the system only to key participants and co-developers and he expected that those individuals at least could recognise the numbers 2 and 5 from handling 500 and 2,000 Communauté Financière Africaine (CFA) banknotes, something that not all their peers have had the opportunity of doing very often.

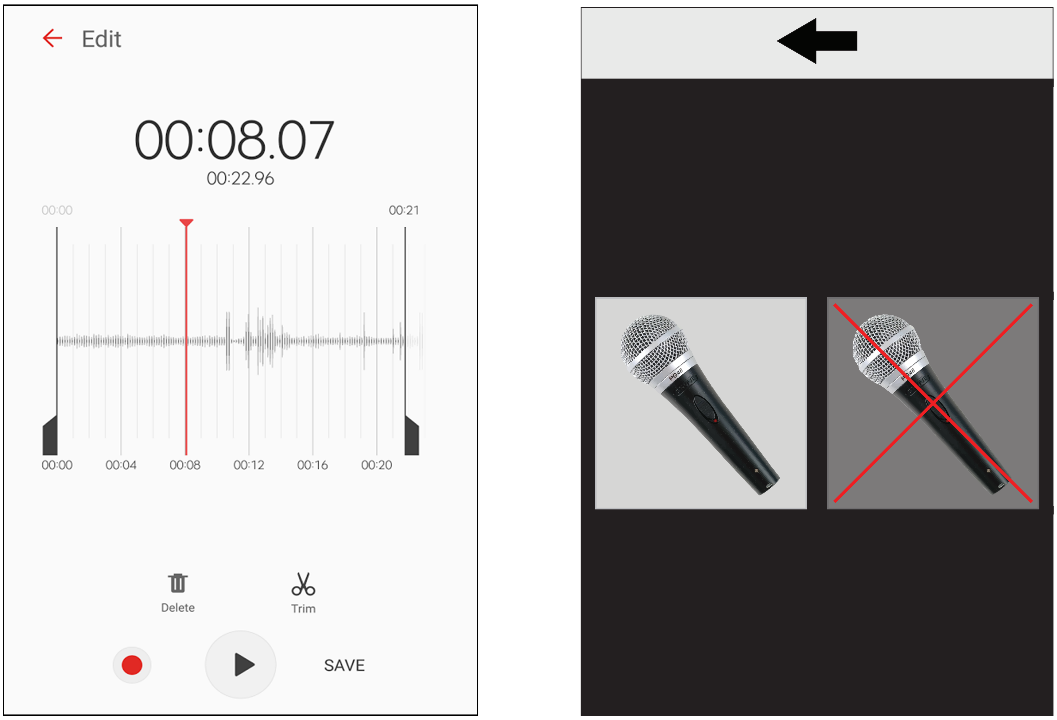
Obviously this method was not very accurate. Multiple factors could influence the accuracy of the estimated position: GPS signal reception conditions, nearby magnetic fields, human errors in the estimation of direction and distance, and finally the rather loosely defined dimensions of football pitches in logging towns. Nevertheless, this method allowed recording of a reasonable indication of the position of potentially dangerous places. This was the key information that the relevant stakeholders would require in their efforts against poachers.

To visualise observations made from a distance, a rudimentary prototype tool was developed using the Google Maps API. As illustrated by figure B.6, this tool indicates the approximate position of the intended place in yellow, as well as the observer's own position in red. The diameter of the red circle is determined by the GPS accuracy. A black arrow represents the compass bearing and the approximate distance the user indicated. To account for errors affecting the bearing and distance estimation, error percentages can be manually adjusted on the right, after which the yellow area will be redrawn accordingly. This prototype was aimed at literate participants only. Eventually this sort of interface could be used by trusted partners of the Mbendjele, or local authorities, to give directions to eco-guards to help them find poacher's camps that were spotted from a distance.

Figure B.6.: Visualisation tool for places observed from an estimated distance. *Map layer © Google Maps.*

B.4.3 Multimedia

By default, ODK Collect relies on the standard Android applications for audio recording (figure B.7a), taking photos and recording videos. However, these interfaces contain textual elements and a multitude of features and settings, all of which are confusing and distracting for non-literate users. To tackle this issue and meet requirement FR-G-5, ODK Collect was extended with a new minimalistic audio recording interface, shown in figure B.7b. In this interface, there were only three buttons: the back button (consistent with the decision tree interface); the record button which was represented by a microphone, a familiar concept to some members of the tribe; and finally the stop button.



(a) Default audio recording interface. © *Samsung Electronics*

(b) Audio recording interface.

Figure B.7.: User interfaces for audio recording.

A replacement for the standard photo/video camera application was planned but had not been developed at that point due to time restrictions. However, it was clear that it had to be done in the near future so that all aspects of the data collection process become equally effortless and comprehensible. As described in chapter 7, in the second prototype, the standard camera application was replaced with a custom one.

B.5 New requirements

Table B.4.: New and recurring functional requirements for Anti-Poaching tool

Req. #	Priority	Description	Rationale
General			
FR-G-6	High	Recurring from table B.1: The system should enable transmission of the collected observations to a centralised database and support multi-modal and automatic transmission.	Urgency was an important factor when working with projects as the one of collecting evidence of poachers' whereabouts, so there was a pressing need for a transmission mechanism that could function under no-internet connectivity and utilising the sparse mobile network existing in the area.
FR-G-7	High	Recurring from table B.1: The system shall enable easy modification of the icons.	A UCD approach on the design of the project would many times lead to changes in either the icons or the structure of the tree. Modifying the project on spot could facilitate this process.
FR-G-8	High	Recurring from table B.1: The system shall enable easy modification of the decision tree.	—"—
Usability			
FR-U-7	High	The system shall support a cancellation button that leads the user to the '*home*' screen of the decision tree.	This would allow users to quickly cancel the current observation and return to the '*home*' screen, without the need of pressing the back button multiple times.
FR-U-8	High	The system shall provide a confirmation screen.	This would allow users to acknowledge that they reached at the end of an observation and their action is needed to either save or discard the observation.
FR-U-9	High	The system shall allow optional fields.	This would allow users to skip questions without providing an answer.

Req. #	Priority	Description	Rationale
FR-U-10	High	The system shall provide a camera UI, appropriate for non-literate participants.	An alternative, simpler and text-free version of the camera would enable non-literate participants to capture photos and provide additional evidence.
FR-U-11	High	The system shall prevent user from pressing the device's home button.	Whenever the '*Home*' button of the device was pressed, the user was transferred away from the data collection application to the system's main UI, which was confusing and distracting.

C Review of data collection platforms

This appendix evaluates a list of data collection platforms in order to assess whether they are appropriate to cover the functional requirements identified in chapter 6. In appendix C.1, the evaluated platforms are described, while appendix C.2 presents the evaluation criteria and the results.

C.1 Platforms

In 2012, there are numerous mobile data collection platforms, and project NOMAD is an attempt to categorise and organise them into one website and provide assistance to humanitarian and development NGOs in selecting the appropriate tools for their needs. Their list of platforms counts 31 providers that promise to offer mobile data collection solutions (NOMAD, 2013). From that list, I identified ten key providers that stand out because of their *sophistication* and *popularity*. Sophistication is used to describe the functionalities a solution could offer; while popularity was measured by the number of projects using a specific solution provider, the magnitude of the projects relying on that solution and lastly the size of the active community that was supporting and maintaining the software.

The reviewed tools are:

- CyberTracker (discussed in appendix C.1.1)
- EpiCollect (discussed in appendix C.1.2)
- FrontlineSMS (discussed in appendix C.1.3)
- imogene (discussed in appendix C.1.4)
- KoBo (discussed in appendix C.1.5)
- Magpi (discussed in appendix C.1.6)
- ODK (discussed in appendix C.1.7)
- OpenXdata (discussed in appendix C.1.8)
- Poimapper (discussed in appendix C.1.9)
- RapidSMS (discussed in appendix C.1.10)

C.1.1 CyberTracker

CyberTracker is an example of early, PDA-based platforms that was developed in 1997 to be used by non-literate animal trackers to record observations (Spinney, 1998; Hartung et al., 2010), but evolved into a general purpose data collection tool that has found many applications relating to conservation and indigenous people (Parr et al., 2002; Douman, 2006; Ansell and Koenig, 2011; Ens, 2012). Nowadays it is outdated, primarily because it relies on expensive and equally outdated PDA devices that lack the processing power and built-in sensors of today's smartphones. Currently there is an effort underway to port CyberTracker to Android and recently there has been released a beta version (Cybertracker, 2015). However, this version, which is ported from Windows Mobile to Android, does not take full advantage of modern Android features. Also the ported UI was initially designed for low-resolution PDA screens and does not look optimal on modern devices (figure C.1).

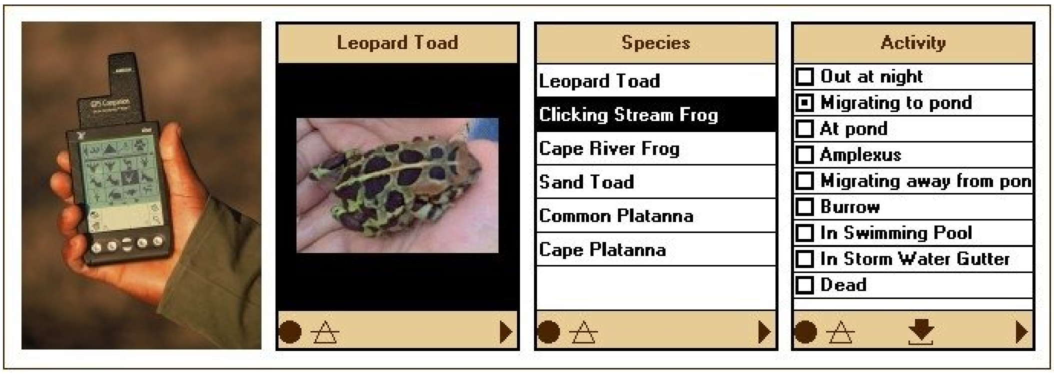


Figure C.1.: CyberTracker's User Interface. *Source: Cybertracker (2015).*

C.1.2 EpiCollect

EpiCollect is an open source initiative of Imperial College London and is primarily geared towards epidemiological and ecological studies (Aanensen et al., 2009; Madder et al., 2012; Imperial College London, 2015). It facilitates form-based data collection in the field using smartphones, supporting both Android and iOS devices, from where results can be uploaded to a central database (figure C.2). A web-based console enables the generation of basic visualisations, including charts, maps and graphs.

C.1.3 FrontlineSMS

FrontlineSMS is an open source platform that allows data collection through SMS messages. The platform is composed of desktop-based software that manages the

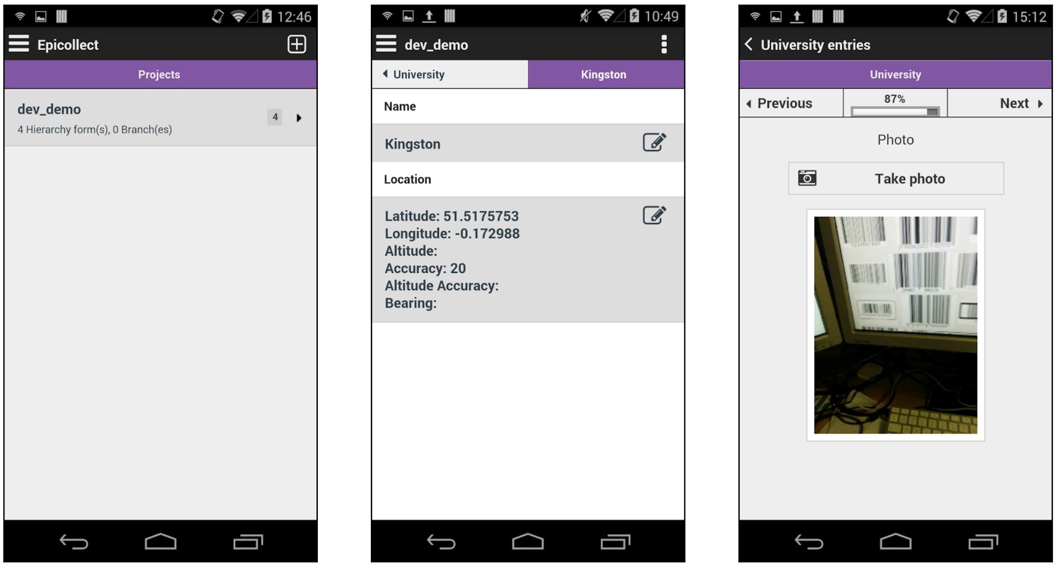


Figure C.2.: EpiCollect. *Source: Imperial College London (2015).*

users and allows the creation and deployment of SMS surveys (figure C.3) (FrontlineSMS, 2015). FrontlineSMS supports add-on modules such as the FrontlineForms which allows users to complete more advanced Java-based forms – that run on any Java-enabled mobile device – and send them via SMS (FrontlineForms, 2015).

C.1.4 imogene

Imogene is an open source set of tools that allows the creation and deployment of data collection information systems (Imogene, 2015). It consists of computer and Android-based software for designing projects and collecting the information respectively (figure C.3). It also contains Web-server based software to collect and store the information. The main difference of imogene is that its tools are built as a plug-in for Eclipse, a multi-language Integrated development environment (IDE) and although most of the project design could be carried out by the graphical interface, Java code could be used to implement more advanced functionalities. Therefore, with the use of a graphical interface, the project manager can develop apps that run on Android and can be used for data collection.

C.1.5 KoBo

KoBo is an open source data collection tool developed by the Harvard Humanitarian Initiative (HHI). Based on ODK Collect (see appendix C.1.7) and Purc forms, KoBo consists of tools to create projects, collect information, upload the data to a server and finally visualise them on a map (figure C.5) (KoBo, 2015).

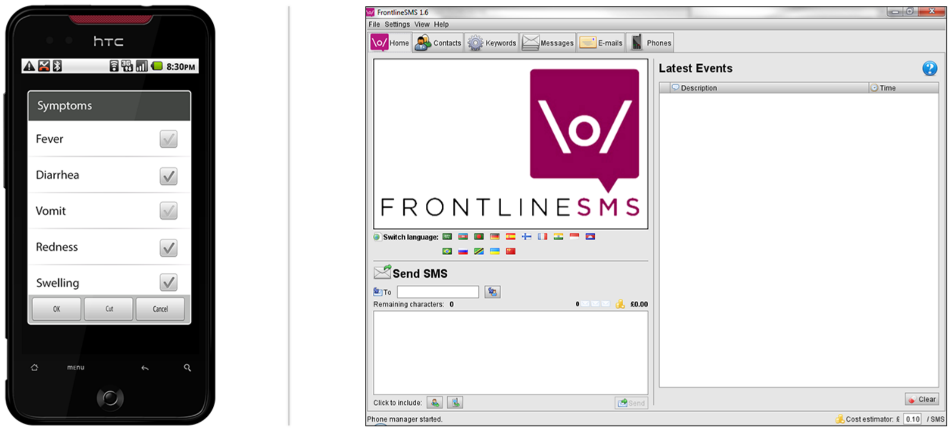


Figure C.3.: Imogene UI on the left and FrontlineSMS Management App on the right. *Source: Imogene (2015) & FrontlineSMS (2015).*

C.1.6 Magpi

Magpi, formerly known as EpiSurveyor, is a proprietary set of data collection tools developed by DataDyne (figure C.6) (Magpi, 2015a). Magpi offers a web-based design tool for creating and managing projects, as well as visualising the incoming data. The platform is initially provided as a free service with some limitations on the uploads per month or the amount of stored data (Magpi, 2015b).

C.1.7 Open Data Kit (ODK)

ODK, is developed as part of an open source project led by the University of Washington (Hartung et al., 2010; Rajput et al., 2012; Open Data Kit, 2015b). The ODK platform is designed to be modular and consists of tools such as ODK Build, Collect (figure C.7), Aggregate, Manage, which cover various aspects of the data collection process. For instance, ODK Build allows users to design form-based surveys, which are described in a format based on the XForms standard (W3C, 2003, 2015). These surveys can then be deployed to Android devices running the ODK Collect application, which facilitates the actual data collection and the uploading of results to a central database. At this central point ODK Aggregate and ODK Manage may be used to visualise, analyse and manage incoming data.

C.1.8 OpenXdata

OpenXdata is an open source platform for creating, managing and deploying data collection software in Java-enabled devices (OpenXdata, 2015a). The OpenXdata server, which can be installed on web server or on a local desktop, allows managers to create complex forms in a graphical user interface and export them to Java-enabled phones or at Android-based devices using ODK Collect for rendering the forms (OpenXdata, 2015b).

C.1.9 Poimapper

Poimapper is a proprietary, cloud-based service that allows the online definition of projects and forms for mobile data collection (Poimapper, 2015a). The forms can be downloaded to Android-based devices and permit the offline data collection in the field (figure C.4). The service starts with a free package and has some limitations on the transactions per user and per month (Poimapper, 2015b).

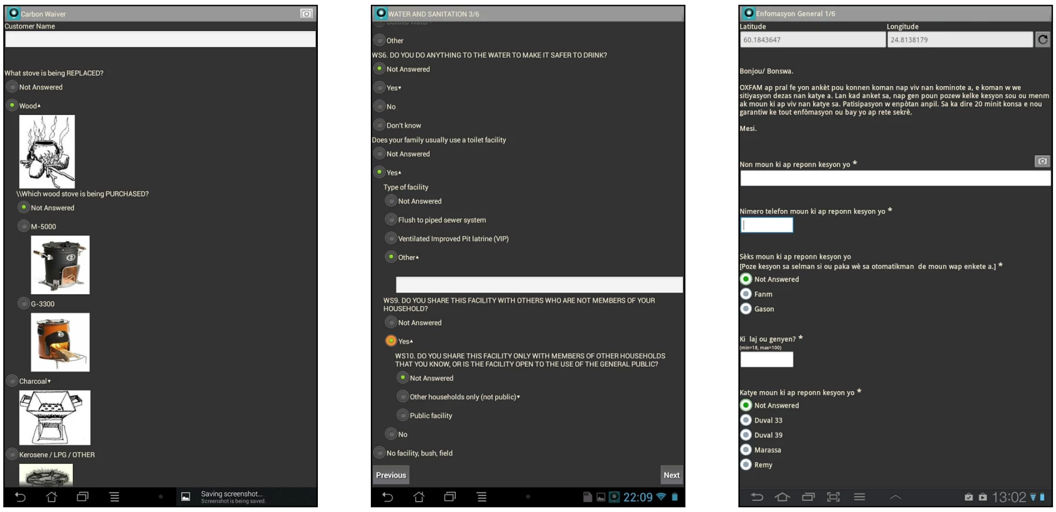


Figure C.4.: Poimapper User Interface. *Source: Poimapper (2015a).*

C.1.10 RapidSMS

RapidSMS is an open source initiative of the United Nations Children's Fund (UNICEF), for collecting rapidly information via SMS messages (RapidSMS, 2015). The platform consists of the web-based application that resides on a server and is responsible for managing the user groups, and for creating and sending the SMS surveys.

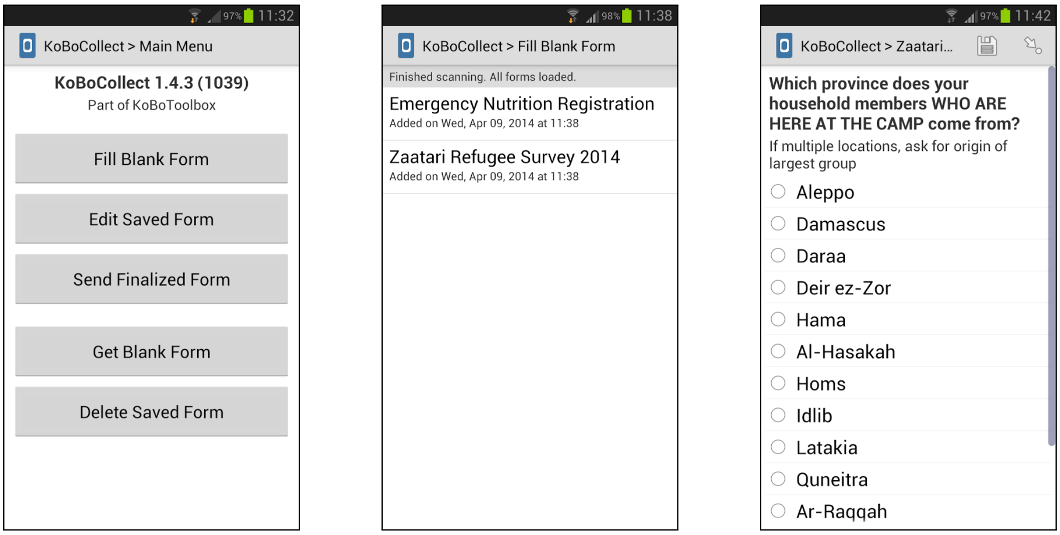


Figure C.5.: KoBo Collect. *Source: KoBo (2015).*

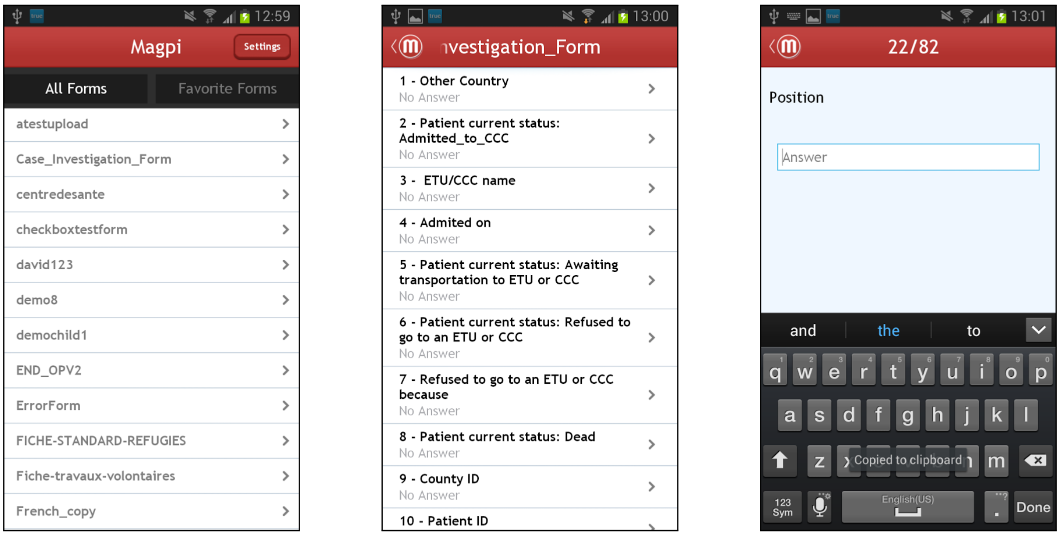


Figure C.6.: Magpi data collection app. *Source: Magpi (2015a).*

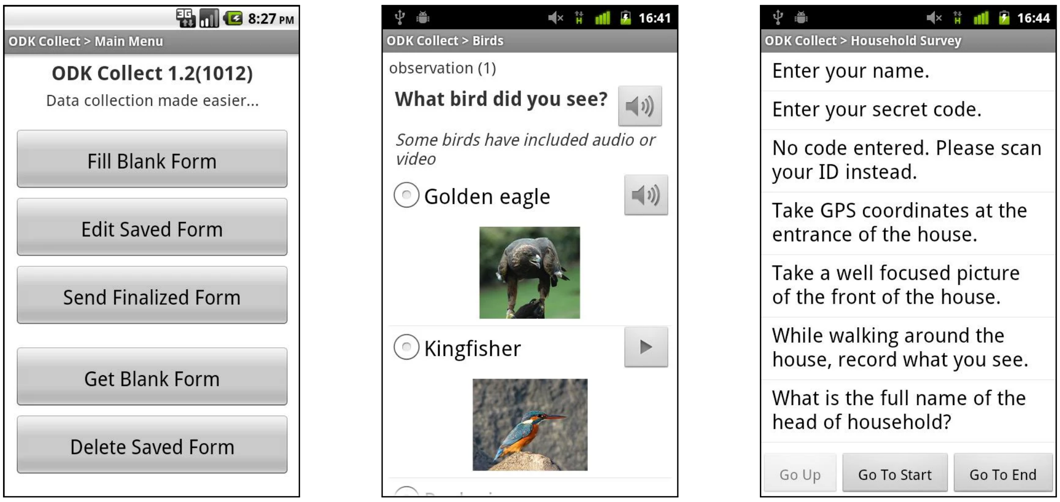


Figure C.7.: ODK Collect User Interface. *Source: Open Data Kit (2015b).*

C.2 Evaluation

In the following section, a brief review of the platforms is presented along with their advantages but also with their limitations and restrictions. The main review criteria relevant to projects dealing with development, environmental justice, conservation efforts, etc. include project management, form features, synchronisation, sensor capabilities, costs and finally data visualisation and analysis capabilities.

C.2.1 Management

The first and one of the most important criteria is the simplicity of the platform and the tools it offers to managers to create and maintain projects. Platforms were evaluated according to the project creation and management tools they offer, the IT knowledge (e.g. programming, setting-up and maintaining servers) that is required to create or modify existing projects and the support they offer to managers.

The evaluated platforms can be roughly separated by the IT knowledge they require (table C.1). On one hand there are providers who offer easy to use solutions, usually requiring a simple registration to their website, along with form generation tools that allow managers to create their own projects. On the other hand, other providers require the downloading and installation of a series of software components, which typically require at least basic IT skills. In general, the most sophisticated solutions that offer more broad options and allow managers to customise projects in many different ways, need more IT knowledge compared to the simple solutions. For example, ODK offers a straightforward tool for defining projects and creating forms that could be sufficient for simple cases. However, for more complex projects, more advanced computer skills are required to use tools such as XLSForm, a tool for creating ODK forms by using an Excel spreadsheet to define the structure (Open Data Kit, 2015c). Furthermore, in more advanced projects even XLSForm might prove insufficient to define the project structure and programming skills are required to directly modify the XForms files of the project (Vitos et al., 2012; Stevens et al., 2013b; Vitos et al., 2013).

Some providers such as EpiCollect, Magpi and Poimapper aim for simplicity and provide their solution under the Software as a Service (SaaS) model. This means providers undertake the responsibility of installing and maintaining a back-end database and sometimes they even offer assistance on the creation of the forms and projects. EpiCollect, as an open source project, could also be used on a self-hosted server rather than a SaaS solution, albeit in this case some IT expertise is

Table C.1.: Project management – Expertise required to set up a new project.

PROVIDER	Level of IT needed	Support
CyberTracker	Low	Online documentation and support by community users
EpiCollect	Low	Online documentation and no active community outside the developers
FrontlineSMS	Moderate	Online documentation and support by community users
imogene	High	Online documentation and support by community users
KoBo	Moderate	Online documentation and support by community users
Magpi	Low	Commercial and forum support
Open Data Kit	High	Online documentation and support by community users
OpenXdata	High	Online documentation and support by community users
Poimapper	Low	Commercial support
RapidSMS	High	Online documentation and support by community users

required to set-up the server, install the software and maintain both the server and the software.

Finally, another comparison measure of the ease of use of each platform is the support that is provided to managers. Almost all the providers supply online documentation with brief or more detailed examples on how to set-up the platforms, create new projects, use their applications and manage the collected information (table C.1). The majority of the providers also supply community forums or online, support groups, where more experienced users or the software developers offer their insight and advice to others by answering questions, pointing out to similar implementations and writing tutorials (table C.1).

C.2.2 Features

Another important parameter for choosing the appropriate platform is the form features that it supports. Digital forms can be composed of different information type elements such as text, numeric, date and location, and depending on the platform they can have different features such as sub-forms, mandatory questions, data range and validation, and skip patterns. For instance, data validation could prevent a surveyor from providing a negative age, and data range could prevent a surveyor from providing a month that is not in the range from 1 to 12 etc. All these elements are important and offer managers versatile tools to create their projects and most of the platforms support the majority of them.

However, the majority of platforms are designed to be used as an alternative to paper-based forms and thus support the creation of sequential forms, where users have to answer one by one a set of questions until they reach the end of the form. The more advanced tools, like the ones selected for comparison, support skip patterns. In these, depending on an answer, a subset of questions could be skipped, but still the order is sequential. For instance, in a simple survey with 5 questions about consumers' habits, there could be a question asking if the participant does smoke. If he does, then the next question could be how many cigarettes per day, and if he does not then this question could be skipped. However, the order is sequential as the 5 questions will be asked one after the other, except for the one with the cigarettes per day that may be skipped.

Table C.2.: Form features.

PROVIDER	Icon based interfaces	Decision Tree Support
CyberTracker	Yes, still has some textual information	Yes, through complex filter option
EpiCollect	No	No
FrontlineSMS	No, SMS based system	No, SMS based system
imogene	No	No
KoBo	No	No
Magpi	No	No
Open Data Kit	Yes, still has some textual information	Yes, with a verbose XML, full of skip patterns and constraints
OpenXdata	No	No
Poimapper	No	No
RapidSMS	No, SMS based system	No, SMS based system

In projects where there is a need to overcome the literacy barrier or to simplify the data collection procedure (see section 3.2), a decision tree with pictorial icons as the one described in section 6.4 could prove to be a more appropriate approach (Lewis and Nelson, 2006; Lewis, 2012b; Lewis and Nkuintchua, 2012). From the existing tools, almost none of them support decision trees with pictorial based interfaces (table C.2). CyberTracker is the only one supporting such interfaces, although the final outcome still contains some textual elements. A more recent mobile data collection platform that partially supports decision trees is ODK; however, it requires verbose and complex XForms (W3C, 2003, 2015) structures to implement them and therefore it needs high level of technical expertise to set up. Also, due to extensive use of textual elements in the UI, the standard ODK Collect application would be too confusing for non-literate users. However, because it is open source, ODK Collect was selected as the basis for the first prototype platform and was modified to suit the project's needs as described in chapter 6 (Vitos et al., 2012; Stevens et al., 2013b; Vitos et al., 2013).

Finally, two tools that need special mention are FrontlineSMS and RapidSMS which may have poor form elements; however, they operate in a different way and are mostly used to collect as well as to broadcast data via SMS messages. They both allow managers to send mass SMS messages to groups of telephone numbers for informative purposes, to create automated replies to incoming SMS messages and finally to conduct polls by filtering the incoming messages by specific keywords.

C.2.3 Synchronisation

Depending on the nature of the project, data synchronisation could be one of the most difficult challenges to tackle. Synchronisation could refer to both transferring the collected information to a central database and to the distribution of projects from a manager's office to the mobile devices in the field.

The majority of mobile data collection tools allow the users to collect information in an offline mode and enable asynchronous (data could be sent at a later stage) data transmission to central databases (table C.3). Most systems rely on Internet connection – via cellular networks (2G/3G/4G) or Wi-Fi – or physical connection to a computer via cables, while FrontlineSMS and RapidSMS use SMS messaging instead. Also the kind of the database used for storing the data varies from relational SQL databases to cloud services such as Google App Engine which offers a cloud computing platform and supports GQL databases (Google, 2015a). Also some tools allow bidirectional syncing that enables devices in the field to download and visualise the information collected up that point.

Regarding the project synchronisation, the majority of the tools offer Internet updates (either via Wi-Fi or cellular networks). Also, it is possible to update the projects via physically connecting the device to a computer and transferring the appropriate project files.

However, all the evaluated tools depend on human interaction for starting the synchronisation process and none of them supports multi-modal data synchronisation

Table C.3.: Data synchronisation.

PROVIDER	Offline Data Collection	Data Transmission	Bidirectional Sync
CyberTracker	Yes	No wireless synchronisation, connection to computer required	No
EpiCollect	Yes	Synchronisation via Internet	Yes
FrontlineSMS	Yes	SMS surveys	No
imogene	Yes	Synchronisation via Internet	Yes
KoBo	Yes	Synchronisation via Internet	No
Magpi	Yes	Synchronisation via Internet	No
Open Data Kit	Yes	Synchronisation via Internet	No
OpenXdata	Yes	Synchronisation via Internet	No
Poimapper	Yes	Synchronisation via Internet	Yes
RapidSMS	Yes	SMS surveys	No

depending on the availability. Most of these tools were designed to be used by literate people in areas of the world that there is always Internet connectivity, for instance EpiCollect as we described in appendix C.1.2 was designed for epidemiologists in the field and can upload data to a central database. Hence, because it was geared towards literate scientists, it is heavily dependent on textual interaction and does not allow automatic data upload via the best means relying on the conditions.

In the context of managing projects in the LICs, where Internet connectivity is rare or not existent, text SMS messages are sometimes a one-way approach for transmitting information. FrontlineSMS and RapidSMS are utilising the SMS system to collect information but are relying on users to write the appropriate keywords into SMS messages and send them to predefined numbers. That task adds many layers of complexity for low or non-literate people. None of the tools is using SMS system as means to send collected information without user interaction.

C.2.4 Sensor Capabilities

Today's mobile phones are usually equipped with various embedded sensors, such as an accelerometer, digital compass, gyroscope, GPS, microphone, and camera, which allow richer data collection. Consequently, most of the platforms make use of these capabilities in order to allow users to add extra information to their records such as photos, videos, audio recordings or their location. The utilisation of embedded sensors provides the possibility to easily add contextual information without the need of any textual input and is therefore especially useful when working with non-literate populations (Lane et al., 2010).

Apart from the solely SMS based systems FrontlineSMS and RapidSMS, all of the reviewed tools support location recording (table C.4). Recent smartphones provide various ways of location recording, using either GPS, Wi-Fi, or GSM, with decreasing levels of accuracy (Ganti et al., 2011). Most of the data collection tools support GPS only, which causes high battery consumption but provides the highest accuracy when being used in an open air space (Milette and Stroud, 2012).

Table C.4.: Sensors support.

PROVIDER	GPS Support	Picture Support	Audio Support	Video Support
CyberTracker	Yes	Yes	Yes	No
EpiCollect	Yes	Yes	Yes	Yes
FrontlineSMS	No, SMS surveys	No, SMS surveys	No, SMS surveys	No, SMS surveys
imogene	Yes	Yes	Yes	Yes
KoBo	Yes	Yes	Yes	Yes
Magpi	Yes	Yes	Yes	Yes
Open Data Kit	Yes	Yes	Yes	Yes
OpenXdata	Yes	Yes	Yes	Yes
Poimapper	Yes	Yes	Yes	Yes
RapidSMS	No, SMS surveys	No, SMS surveys	No, SMS surveys	No, SMS surveys

Despite the various methods of utilizing GPS with a smartphone, all of the tested solutions capture a single GPS fix. None of them allows the user to set a minimum accuracy or enhance their location with extra information such as direction, orientation and speed.

According to Lane et al. (2010), the camera and microphone are the most powerful and most ubiquitous sensors in the world. Their statement is validated by the findings of this data collection tools evaluation as all the Internet-based tools support photo, video and audio recordings. Only the outdated CyberTracker does not provide the option to record videos.

C.2.5 Costs

As already mentioned, some providers such as EpiCollect, Magpi and Poimapper provide their solution under the SaaS model. Each of these companies has its own pricing model which depends on the company's strategy and goals. In general, these services are provided for a fee, either based on the number of users or the amount of data collected per month or annually (Magpi, 2015b; Poimapper, 2015b). From the selected list, Magpi and Poimapper are proprietary and offer their solutions for a fee. The rest of the platforms are offered either for free such as CyberTracker, or are open source initiatives.

Of course, to these costs an organisation should also add operational costs, the price of the devices and finally the cost for setting up a server to collect the information. Furthermore, depending on the location and the extend of the survey, there is another added cost for transmitting the data to the central database either via mobile Internet, Wi-Fi or SMS.

C.2.6 Data visualisation and analysis

An end-to-end data collection solution is not over when the data is stored in a database. Most importantly, the data needs to be fed back to the manager of the system and to the end surveyor. Most tools additionally provide a graphical data representation in the form of maps or graphs. Aaron Koblin, head of the Data Arts Team in Google's Creative Lab, claims that:

> *Scientists have an amazing quantity of data, but their presentation can drain the meaning and power from it. They sometimes get stuck on the data, and don't work up to information, knowledge and wisdom in their communications (Hoffman, 2012).*

The general aim of collecting data is to provide an understanding to the user. Data visualisation and analysis should facilitate this process.

The visualisation tools vary in their features, e.g. graphs, maps, data filtering, the generation of reports and the possibility to export the data for further analysis (table C.5). The results show that most of the reviewed tools provide a very basic database interface which lists the collected data in a table format. Additionally, simple plot functions are supported to show the data on a map or as a graph but with no or very limited possibilities for customisation. For in-depth data analysis files can be exported which allow the data to be used with more advanced statistical or GIS software packages.

Table C.5.: Data visualisation and analysis.

PROVIDER	Query results	Map support	Graph support	Export formats
CyberTracker	Yes	Yes	Yes	CSV, ESRI Shapefile, KML, XML
EpiCollect	Yes	Yes	Yes	CSV, XML
FrontlineSMS	Displays SMS	No	No	CSV
imogene	Yes	Yes	No	No
KoBo	Yes	Yes	Yes	CSV
Magpi	Yes	Yes	Yes	TXT, MDB, XLSX
Open Data Kit	Yes	Yes	Yes	CSV, KML
OpenXdata	Basic, Excel like representation	No	No	CSV
Poimapper	Yes	Yes	Yes	XLSX, DOCX, CSV, KML
RapidSMS	Basic with RapidSMS XForms	No	No	CSV

Feature-wise, the most advanced solution in the review is KoBo Maps, which supports spatial data aggregation and interactive maps. However, these are limited to pre-processed queries. None of the reviewed tools was able to carry out on-the-fly spatial analysis and thus provide more meaningful insights. For instance, imagine health workers conducting surveys on health conditions of rural communities in Africa, being able to query their mobile devices for relevant information such as which the nearest hospital is, what kind of facilities it provides and consequently better advice the participants.

C.3 Conclusion

To sum up, there are a myriad of mobile data collection platforms available on the digital market today and almost all of them offer similar functionalities, covering the requirements of analogous use cases. The purpose of the ten tools, evaluated in this thesis, is often to digitise existing paper-based forms, facilitate the data collection procedure by eliminating errors, applying data constraints and validation, and standardise the process. As a result, these applications are generally targeting literate user populations with at least basic computer operational skills, or in areas with easy access to infrastructures such as power and Internet.

When it comes to data collection that would allow low or non-literate users, with non-existing computer skills to collect and distribute information, none of the platform offer a complete solution that would provide:

- Text free, pictorial based interfaces.
- Support of flexible and automated data sync.
- Data visualisation tools.
- Tools for easy project development without the need of IT expertise based on a SaaS model.

Anti-Poaching XForms

D

Listing D.1 demonstrates the code needed to construct a decision tree structure using the ODK *XForms* format for the prototype of an Anti-Poaching case study, as presented in chapter 6.

Listing D.1: Anti-Poaching XForms implementation

```
<h:html xmlns="http://www.w3.org/2002/xforms" xmlns:ev="http://www.w3.org/2001/xml-events" xmlns:h="http://www.w3.org/1999/xhtml" xmlns:jr="http://openrosa.org/javarosa" xmlns:orx="http://openrosa.org/xforms/" xmlns:xsd="http://www.w3.org/2001/XMLSchema">
  <h:head>
    <h:title>AntiPoaching</h:title>
    <model>
      <itext>
        <translation default="true()" lang="default">
          <text id="/AntiPoaching/pressed_4/4.1:label">
            <value form="image">jr://images/4.1.jpg</value>
            <value>4.1</value>
          </text>
          <text id="/AntiPoaching/pressed_5.2.4/audio:label">
            <value form="image">jr://images/_audio.jpg</value>
            <value>audio</value>
          </text>
          <text id="/AntiPoaching/pressed_home/5:label">
            <value form="image">jr://images/5.jpg</value>
            <value>5</value>
          </text>
          <text id="/AntiPoaching/pressed_1.1/1.1.2:label">
            <value form="image">jr://images/1.1.2.jpg</value>
            <value>1.1.2</value>
          </text>
          <text id="/AntiPoaching/pressed_5.1/5.1.3:label">
            <value form="image">jr://images/5.1.3.jpg</value>
            <value>5.1.3</value>
          </text>
          <text id="/AntiPoaching/pressed_1.2.3/audio:label">
            <value form="image">jr://images/_audio.jpg</value>
            <value>audio</value>
          </text>
          <text id="/AntiPoaching/pressed_home/2:label">
            <value form="image">jr://images/2.jpg</value>
            <value>2</value>
          </text>
```

```
        <text id="/AntiPoaching/pressed_2.6/2.6.2:label">
          <value form="image">jr://images/2.6.2.jpg</value>
          <value>2.6.2</value>
        </text>
        <text id="/AntiPoaching/pressed_1.1/1.1.1:label">
          <value form="image">jr://images/1.1.1.jpg</value>
          <value>1.1.1</value>
        </text>
        <text id="/AntiPoaching/pressed_home/6:label">
          <value form="image">jr://images/6.jpg</value>
          <value>6</value>
        </text>
        <text id="/AntiPoaching/pressed_1.4.4/audio:label">
          <value form="image">jr://images/_audio.jpg</value>
          <value>audio</value>
        </text>
        <text id="/AntiPoaching/pressed_1.3/1.3.1:label">
          <value form="image">jr://images/1.3.1.jpg</value>
          <value>1.3.1</value>
        </text>
        <text id="/AntiPoaching/pressed_1.3.2/audio:label">
          <value form="image">jr://images/_audio.jpg</value>
          <value>audio</value>
        </text>
        <text id="/AntiPoaching/pressed_3/3.2:label">
          <value form="image">jr://images/3.2.jpg</value>
          <value>3.2</value>
        </text>
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          <value>1.2.1</value>
        </text>
        <text id="/AntiPoaching/pressed_1.2/1.2.3:label">
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          <value>1.2.3</value>
        </text>
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          <value form="image">jr://images/5.2.3.jpg</value>
          <value>5.2.3</value>
        </text>
        <text id="/AntiPoaching/pressed_6.1/6.1.5:label">
          <value form="image">jr://images/_audio-video.jpg</value>
          <value>6.1.5</value>
        </text>
        <text id="/AntiPoaching/pressed_1.3.2/video:label">
          <value form="image">jr://images/_video.jpg</value>
          <value>video</value>
        </text>
        <text id="/AntiPoaching/pressed_6.1/6.1.2:label">
          <value form="image">jr://images/6.1.2.jpg</value>
          <value>6.1.2</value>
```

```
        </text>
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          <value>3.1</value>
        </text>
        <text id="/AntiPoaching/pressed_5.3.4/video:label">
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        </text>
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        </text>
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        </text>
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        </text>
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        </text>
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          <value>2.6.1</value>
        </text>
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          <value form="image">jr://images/1.jpg</value>
```

```xml
          <value>1</value>
        </text>
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        </text>
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        <text id="/AntiPoaching/pressed_6.1.5/video:label">
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        </text>
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        </text>
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```

```
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    </text>
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        </text>
        <text id="/AntiPoaching/pressed_6/6.2:label">
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          <value>6.2</value>
        </text>
        <text id="/AntiPoaching/pressed_5.1.4/video:label">
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          </text>
          <text id="/AntiPoaching/pressed_1.2.3/video:label">
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```
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        </text>
      </translation>
    </itext>
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        <end/>
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        <pressed_home/>
        <pressed_1/>
        <pressed_2/>
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        <pressed_4/>
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        <pressed_6.1.4/>
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        <pressed_1.3.2.1/>
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        <pressed_1.4.4.1/>
        <pressed_1.4.4.2/>
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      <pressed_5.2.4.2/>
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      <pressed_6.1.5.2/>
      <pressed_6.2.5.1/>
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  <bind jr:preload="date" jr:preloadParams="today" nodeset="/AntiPoaching/today" type="date"/>
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  <bind jr:preload="property" jr:preloadParams="subscriberid" nodeset="/AntiPoaching/subscriberid" type="string"/>
  <bind jr:preload="property" jr:preloadParams="simserial" nodeset="/AntiPoaching/simid" type="string"/>
  <bind jr:preload="property" jr:preloadParams="phonenumber" nodeset="/AntiPoaching/phonenumber" type="string"/>
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  <bind nodeset="/AntiPoaching/pressed_2" relevant="/AntiPoaching/pressed_home = &quot;2&quot;" required="true()" type="select1"/>
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  <bind nodeset="/AntiPoaching/pressed_1.3" relevant="/AntiPoaching/pressed_1 = &quot;1.3&quot;" required="true()" type="select1"/>
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    &quot;6.2&quot;" required="true()" type="select1"/>
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```
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<bind nodeset="/AntiPoaching/pressed_1.4.1" relevant="/AntiPoaching/pressed_1.4 = &quot;1.4.1&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_1.4.2" relevant="/AntiPoaching/pressed_1.4 = &quot;1.4.2&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_1.4.3" relevant="/AntiPoaching/pressed_1.4 = &quot;1.4.3&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_1.4.4" relevant="/AntiPoaching/pressed_1.4 = &quot;1.4.4&quot;" required="true()" type="select1"/>
<bind nodeset="/AntiPoaching/pressed_2.6.1" relevant="/AntiPoaching/pressed_2.6 = &quot;2.6.1&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_2.6.2" relevant="/AntiPoaching/pressed_2.6 = &quot;2.6.2&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_3.3.1" relevant="/AntiPoaching/pressed_3.3 = &quot;audio&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_3.3.2" relevant="/AntiPoaching/pressed_3.3 = &quot;video&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_4.5.1" relevant="/AntiPoaching/pressed_4.5 = &quot;audio&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_4.5.2" relevant="/AntiPoaching/pressed_4.5 = &quot;video&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_5.1.1" relevant="/AntiPoaching/pressed_5.1 = &quot;5.1.1&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_5.1.2" relevant="/AntiPoaching/pressed_5.1 = &quot;5.1.2&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_5.1.3" relevant="/AntiPoaching/pressed_5.1 = &quot;5.1.3&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_5.1.4" relevant="/AntiPoaching/pressed_5.1 = &quot;5.1.4&quot;" required="true()" type="select1"/>
<bind nodeset="/AntiPoaching/pressed_5.2.1" relevant="/AntiPoaching/pressed_5.2 = &quot;5.2.1&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_5.2.2" relevant="/AntiPoaching/pressed_5.2 = &quot;5.2.2&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_5.2.3" relevant="/AntiPoaching/pressed_5.2 = &quot;5.2.3&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_5.2.4" relevant="/AntiPoaching/pressed_5.2 = &quot;5.2.4&quot;" required="true()" type="select1"/>
<bind nodeset="/AntiPoaching/pressed_5.3.1" relevant="/AntiPoaching/pressed_5.3 = &quot;5.3.1&quot;" required="true()" type="geopoint"/>
```

```
<bind nodeset="/AntiPoaching/pressed_5.3.2" relevant="/AntiPoaching/pressed_5.3 = &quot;5.3.2&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_5.3.3" relevant="/AntiPoaching/pressed_5.3 = &quot;5.3.3&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_5.3.4" relevant="/AntiPoaching/pressed_5.3 = &quot;5.3.4&quot;" required="true()" type="select1"/>
<bind nodeset="/AntiPoaching/pressed_6.1.1" relevant="/AntiPoaching/pressed_6.1 = &quot;6.1.1&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_6.1.2" relevant="/AntiPoaching/pressed_6.1 = &quot;6.1.2&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_6.1.3" relevant="/AntiPoaching/pressed_6.1 = &quot;6.1.3&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_6.1.4" relevant="/AntiPoaching/pressed_6.1 = &quot;6.1.4&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_6.1.5" relevant="/AntiPoaching/pressed_6.1 = &quot;6.1.5&quot;" required="true()" type="select1"/>
<bind nodeset="/AntiPoaching/pressed_6.2.1" relevant="/AntiPoaching/pressed_6.2 = &quot;6.2.1&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_6.2.2" relevant="/AntiPoaching/pressed_6.2 = &quot;6.2.2&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_6.2.3" relevant="/AntiPoaching/pressed_6.2 = &quot;6.2.3&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_6.2.4" relevant="/AntiPoaching/pressed_6.2 = &quot;6.2.4&quot;" required="true()" type="geopoint"/>
<bind nodeset="/AntiPoaching/pressed_6.2.5" relevant="/AntiPoaching/pressed_6.2 = &quot;6.2.5&quot;" required="true()" type="select1"/>
<bind nodeset="/AntiPoaching/pressed_1.2.3.1" relevant="/AntiPoaching/pressed_1.2.3 = &quot;audio&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_1.2.3.2" relevant="/AntiPoaching/pressed_1.2.3 = &quot;video&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_1.3.2.1" relevant="/AntiPoaching/pressed_1.3.2 = &quot;audio&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_1.3.2.2" relevant="/AntiPoaching/pressed_1.3.2 = &quot;video&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_1.4.4.1" relevant="/AntiPoaching/pressed_1.4.4 = &quot;audio&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_1.4.4.2" relevant="/AntiPoaching/pressed_1.4.4 = &quot;video&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_5.1.4.1" relevant="/AntiPoaching/pressed_5.1.4 = &quot;audio&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_5.1.4.2" relevant="/AntiPoaching/pressed_5.1.4 = &quot;video&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_5.2.4.1" relevant="/AntiPoaching/pressed_5.2.4 = &quot;audio&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_5.2.4.2" relevant="/AntiPoaching/pressed_5.2.4 = &quot;video&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_5.3.4.1" relevant="/AntiPoaching/pressed_5.3.4 = &quot;audio&quot;" required="true()" type="binary"/>
<bind nodeset="/AntiPoaching/pressed_5.3.4.2" relevant="/AntiPoaching/pressed_5.3.4 = &quot;video&quot;" required="true()" type="binary"/>
```

```
    <bind nodeset="/AntiPoaching/pressed_6.1.5.1" relevant="/AntiPoaching/
        pressed_6.1.5 = &quot;audio&quot;" required="true()" type="binary"/>
    <bind nodeset="/AntiPoaching/pressed_6.1.5.2" relevant="/AntiPoaching/
        pressed_6.1.5 = &quot;video&quot;" required="true()" type="binary"/>
    <bind nodeset="/AntiPoaching/pressed_6.2.5.1" relevant="/AntiPoaching/
        pressed_6.2.5 = &quot;audio&quot;" required="true()" type="binary"/>
    <bind nodeset="/AntiPoaching/pressed_6.2.5.2" relevant="/AntiPoaching/
        pressed_6.2.5 = &quot;video&quot;" required="true()" type="binary"/>
  </model>
</h:head>
<h:body>
  <select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_home">
    <label>Home Grid</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_home/1:label')"/>
      <value>1</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_home/2:label')"/>
      <value>2</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_home/3:label')"/>
      <value>3</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_home/4:label')"/>
      <value>4</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_home/5:label')"/>
      <value>5</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_home/6:label')"/>
      <value>6</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_1">
    <label>1</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_1/1.1:label')"/>
      <value>1.1</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_1/1.2:label')"/>
      <value>1.2</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_1/1.3:label')"/>
      <value>1.3</value>
```

```xml
        </item>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_1/1.4:label')"/>
          <value>1.4</value>
        </item>
      </select1>
      <select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_2">
        <label>2</label>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_2/2.1:label')"/>
          <value>2.1</value>
        </item>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_2/2.2:label')"/>
          <value>2.2</value>
        </item>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_2/2.3:label')"/>
          <value>2.3</value>
        </item>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_2/2.4:label')"/>
          <value>2.4</value>
        </item>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_2/2.5:label')"/>
          <value>2.5</value>
        </item>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_2/2.6:label')"/>
          <value>2.6</value>
        </item>
      </select1>
      <select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_3">
        <label>3</label>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_3/3.1:label')"/>
          <value>3.1</value>
        </item>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_3/3.2:label')"/>
          <value>3.2</value>
        </item>
        <item>
          <label ref="jr:itext('/AntiPoaching/pressed_3/3.3:label')"/>
          <value>3.3</value>
        </item>
      </select1>
      <select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_4">
        <label>4</label>
        <item>
```

```
      <label ref="jr:itext('/AntiPoaching/pressed_4/4.1:label')"/>
      <value>4.1</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_4/4.2:label')"/>
      <value>4.2</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_4/4.3:label')"/>
      <value>4.3</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_4/4.4:label')"/>
      <value>4.4</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_4/4.5:label')"/>
      <value>4.5</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_5">
    <label>5</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_5/5.1:label')"/>
      <value>5.1</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_5/5.2:label')"/>
      <value>5.2</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_5/5.3:label')"/>
      <value>5.3</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_6">
    <label>6</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_6/6.1:label')"/>
      <value>6.1</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_6/6.2:label')"/>
      <value>6.2</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_1.1">
    <label>1.1</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_1.1/1.1.1:label')"/>
      <value>1.1.1</value>
```

```
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.1/1.1.2:label')"/>
    <value>1.1.2</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.1/1.1.3:label')"/>
    <value>1.1.3</value>
  </item>
</select1>
<select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_1.2">
  <label>1.2</label>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.2/1.2.1:label')"/>
    <value>1.2.1</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.2/1.2.2:label')"/>
    <value>1.2.2</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.2/1.2.3:label')"/>
    <value>1.2.3</value>
  </item>
</select1>
<select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_1.3">
  <label>1.3</label>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.3/1.3.1:label')"/>
    <value>1.3.1</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.3/1.3.2:label')"/>
    <value>1.3.2</value>
  </item>
</select1>
<select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_1.4">
  <label>1.4</label>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.4/1.4.1:label')"/>
    <value>1.4.1</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.4/1.4.2:label')"/>
    <value>1.4.2</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_1.4/1.4.3:label')"/>
    <value>1.4.3</value>
  </item>
  <item>
```

```
      <label ref="jr:itext('/AntiPoaching/pressed_1.4/1.4.4:label')"/>
      <value>1.4.4</value>
    </item>
  </select1>
  <input ref="/AntiPoaching/pressed_2.1">
    <label>2.1</label>
  </input>
  <input ref="/AntiPoaching/pressed_2.2">
    <label>2.2</label>
  </input>
  <input ref="/AntiPoaching/pressed_2.3">
    <label>2.3</label>
  </input>
  <input ref="/AntiPoaching/pressed_2.4">
    <label>2.4</label>
  </input>
  <input ref="/AntiPoaching/pressed_2.5">
    <label>2.5</label>
  </input>
  <select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_2.6">
    <label>2.6</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_2.6/2.6.1:label')"/>
      <value>2.6.1</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_2.6/2.6.2:label')"/>
      <value>2.6.2</value>
    </item>
  </select1>
  <input ref="/AntiPoaching/pressed_3.1">
    <label>3.1</label>
  </input>
  <input ref="/AntiPoaching/pressed_3.2">
    <label>3.2</label>
  </input>
  <select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_3.3">
    <label>3.3</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_3.3/audio:label')"/>
      <value>audio</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_3.3/video:label')"/>
      <value>video</value>
    </item>
  </select1>
  <input ref="/AntiPoaching/pressed_4.1">
    <label>4.1</label>
  </input>
  <input ref="/AntiPoaching/pressed_4.2">
```

```
  <label>4.2</label>
</input>
<input ref="/AntiPoaching/pressed_4.3">
  <label>4.3</label>
</input>
<input ref="/AntiPoaching/pressed_4.4">
  <label>4.4</label>
</input>
<select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_4.5">
  <label>4.5</label>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_4.5/audio:label')"/>
    <value>audio</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_4.5/video:label')"/>
    <value>video</value>
  </item>
</select1>
<select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_5.1">
  <label>5.1</label>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_5.1/5.1.1:label')"/>
    <value>5.1.1</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_5.1/5.1.2:label')"/>
    <value>5.1.2</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_5.1/5.1.3:label')"/>
    <value>5.1.3</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_5.1/5.1.4:label')"/>
    <value>5.1.4</value>
  </item>
</select1>
<select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_5.2">
  <label>5.2</label>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_5.2/5.2.1:label')"/>
    <value>5.2.1</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_5.2/5.2.2:label')"/>
    <value>5.2.2</value>
  </item>
  <item>
    <label ref="jr:itext('/AntiPoaching/pressed_5.2/5.2.3:label')"/>
    <value>5.2.3</value>
```

```
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_5.2/5.2.4:label')"/>
      <value>5.2.4</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_5.3">
    <label>5.3</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_5.3/5.3.1:label')"/>
      <value>5.3.1</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_5.3/5.3.2:label')"/>
      <value>5.3.2</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_5.3/5.3.3:label')"/>
      <value>5.3.3</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_5.3/5.3.4:label')"/>
      <value>5.3.4</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_6.1">
    <label>6.1</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_6.1/6.1.1:label')"/>
      <value>6.1.1</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_6.1/6.1.2:label')"/>
      <value>6.1.2</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_6.1/6.1.3:label')"/>
      <value>6.1.3</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_6.1/6.1.4:label')"/>
      <value>6.1.4</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_6.1/6.1.5:label')"/>
      <value>6.1.5</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-2" ref="/AntiPoaching/pressed_6.2">
    <label>6.2</label>
    <item>
```

```xml
        <label ref="jr:itext('/AntiPoaching/pressed_6.2/6.2.1:label')"/>
        <value>6.2.1</value>
      </item>
      <item>
        <label ref="jr:itext('/AntiPoaching/pressed_6.2/6.2.2:label')"/>
        <value>6.2.2</value>
      </item>
      <item>
        <label ref="jr:itext('/AntiPoaching/pressed_6.2/6.2.3:label')"/>
        <value>6.2.3</value>
      </item>
      <item>
        <label ref="jr:itext('/AntiPoaching/pressed_6.2/6.2.4:label')"/>
        <value>6.2.4</value>
      </item>
      <item>
        <label ref="jr:itext('/AntiPoaching/pressed_6.2/6.2.5:label')"/>
        <value>6.2.5</value>
      </item>
    </select1>
    <group appearance="field-list" ref="/AntiPoaching/bearing_1.1.1">
      <label>Group with geolocation + bearing</label>
      <input ref="/AntiPoaching/bearing_1.1.1/pressed_1.1.1">
        <label>pressed_1.1.1</label>
      </input>
      <input appearance="bearing" ref="/AntiPoaching/bearing_1.1.1/bearing_pressed_1
          .1.1">
        <label>bearing_pressed_1.1.1</label>
      </input>
    </group>
    <group appearance="field-list" ref="/AntiPoaching/bearing_1.1.2">
      <label>Group with geolocation + bearing</label>
      <input ref="/AntiPoaching/bearing_1.1.2/pressed_1.1.2">
        <label>pressed_1.1.2</label>
      </input>
      <input appearance="bearing" ref="/AntiPoaching/bearing_1.1.2/bearing_pressed_1
          .1.2">
        <label>bearing_pressed_1.1.2</label>
      </input>
    </group>
    <group appearance="field-list" ref="/AntiPoaching/bearing_1.1.3">
      <label>Group with geolocation + bearing</label>
      <input ref="/AntiPoaching/bearing_1.1.3/pressed_1.1.3">
        <label>pressed_1.1.3</label>
      </input>
      <input appearance="bearing" ref="/AntiPoaching/bearing_1.1.3/bearing_pressed_1
          .1.3">
        <label>bearing_pressed_1.1.3</label>
      </input>
    </group>
    <input ref="/AntiPoaching/pressed_1.2.1">
```

```
    <label>1.2.1</label>
  </input>
  <input ref="/AntiPoaching/pressed_1.2.2">
    <label>1.2.2</label>
  </input>
  <select1 appearance="quickcompact-1" ref="/AntiPoaching/pressed_1.2.3">
    <label>1.2.3</label>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_1.2.3/audio:label')"/>
      <value>audio</value>
    </item>
    <item>
      <label ref="jr:itext('/AntiPoaching/pressed_1.2.3/video:label')"/>
      <value>video</value>
    </item>
  </select1>
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    </upload>
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    <input ref="/AntiPoaching/pressed_5.1.3">
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```

```
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      </item>
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</upload>
<upload mediatype="audio/*" ref="/AntiPoaching/pressed_1.3.2.1">
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```

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    </upload>
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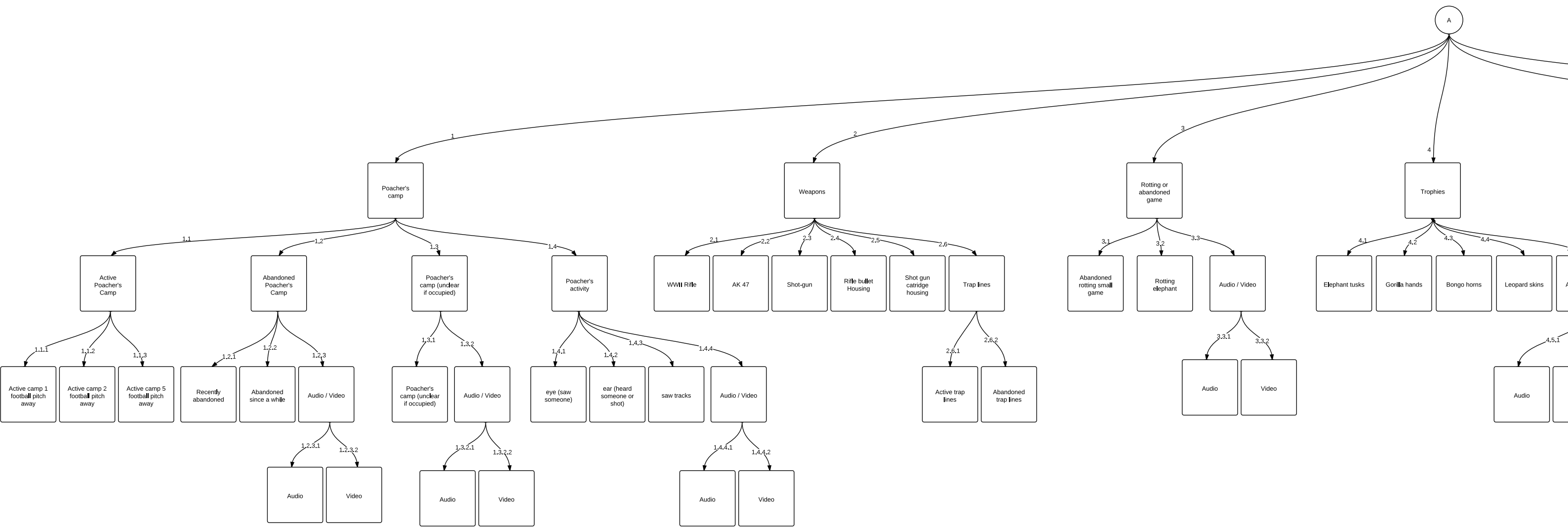
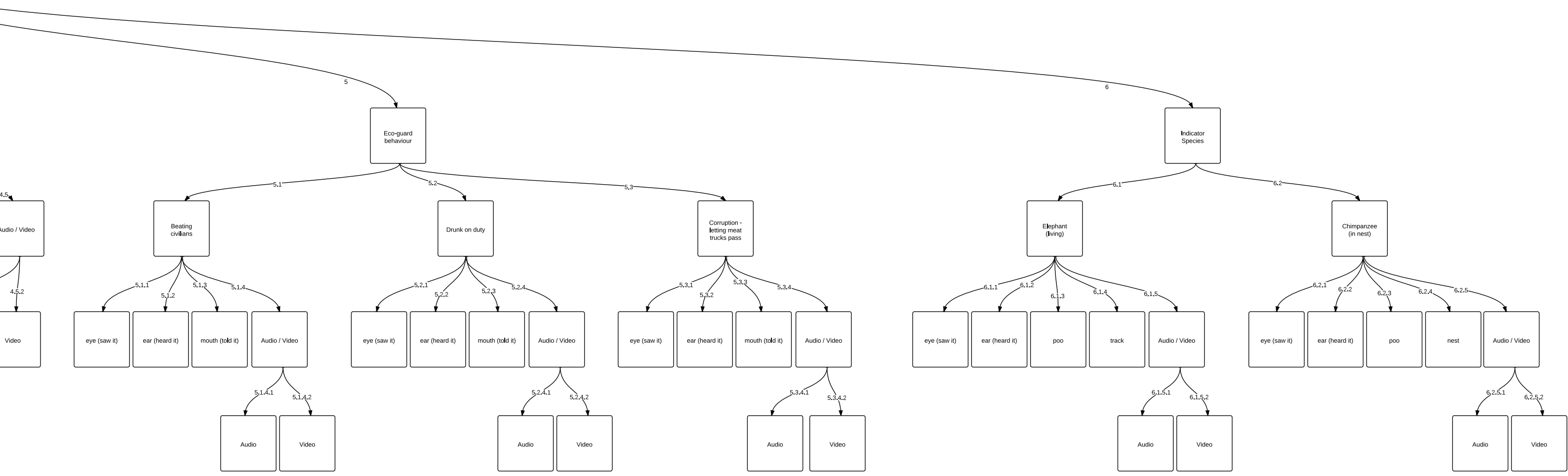
    </upload>
  </h:body>
</h:html>
```

E

Anti-Poaching Decision Tree

Flip to the next page to view the first version of the Anti-Poaching decision tree, consisting of 59 distinct icons spread across 4 levels. If you are reading this document on a computer screen, make sure that your pdf viewer is set to Book View (or the equivalent option of your program) to see the next both pages into one screen.


A
1
2
3
4
Poacher's camp
Weapons
Rotting or abandoned game
Trophies
1.1
1.2
1.3
1.4
Active Poacher's Camp
Abandoned Poacher's Camp
Poacher's camp (unclear if occupied)
Poacher's activity
2.1
2.2
2.3
2.4
2.5
2.6
WWII Rifle
AK 47
Shot-gun
Rifle bullet Housing
Shot gun catridge housing
Trap lines
3.1
3.2
3.3
Abandoned rotting small game
Rotting elephant
Audio / Video
4.1
4.2
4.3
4.4
Elephant tusks
Gorilla hands
Bongo horns
Leopard skins
1.1.1
1.1.2
1.1.3
Active camp 1 football pitch away
Active camp 2 football pitch away
Active camp 5 football pitch away
1.2.1
1.2.2
1.2.3
Recently abandoned
Abandoned since a while
Audio / Video
1.3.1
1.3.2
Poacher's camp (unclear if occupied)
Audio / Video
1.4.1
1.4.2
1.4.3
1.4.4
eye (saw someone)
ear (heard someone or shot)
saw tracks
Audio / Video
2.6.1
2.6.2
Active trap lines
Abandoned trap lines
3.3.1
3.3.2
Audio
Video
4.5.1
Audio
1.2.3.1
1.2.3.2
Audio
Video
1.3.2.1
1.3.2.2
Audio
Video
1.4.4.1
1.4.4.2
Audio
Video


5
6
Eco-guard behaviour
Indicator Species
Audio / Video
Video
Beating civilians
Drunk on duty
Corruption - letting meat trucks pass
Elephant (living)
Chimpanzee (in nest)
eye (saw it)
ear (heard it)
mouth (told it)
Audio / Video
poo
track
nest
Audio
Video

F Case study 2: Participatory monitoring of logging: Technical work

F.1 Requirements

Table F.1.: Functional requirements for data collection platform

Req. #	Priority	Description	Rationale
General			
FR-G-1	High	Recurring from table B.1: The system shall enable forest community participants to collect evidence and information on poaching activity.	—
FR-G-2	High	Recurring from table B.1: The system shall operate on mobile, handheld devices.	Since the system should allow observations in the forest, the devices should be compact and light for participants to carry. Thus, laptops or desktop computers are not applicable because of (a) size, bulkiness; (b) power requirements and (c) lack of sensors such as GPS.
FR-G-3	High	Recurring from table B.1: The system shall be free for interested communities and open source.	The use of affordable equipment and open source technologies would allow the easier adoption of the technology by communities and stakeholders, since the software would be free to use, distribute and modify. Open source technologies would also allow the adaption of the tools developed in other, different contexts by interested communities or stakeholders.

Req. #	Priority	Description	Rationale
FR-G-4	High	Recurring from table B.1: The system shall complement each observation with geographical coordinates from a GPS receiver.	Observations complimented with GPS coordinates could provide reliable evidence for poaching activities.
FR-G-5	High	Recurring from table B.1: The system shall enable users to complement observations with an audio recording, photo or video.	Audio, photos and videos could provide additional information and evidence.
FR-G-6	High	Recurring from table B.1: The system should enable transmission of the collected observations to a centralised database.	Syncing of collected information to a central database and providing access to relevant stakeholders would enable better monitoring of poaching activities.
FR-G-7	High	Recurring from table B.1: The system shall enable easy modification of the icons (In accordance with FR-U-1 and FR-U-2).	Data collection projects are work in progress and the icons might change due to participants' lack of understanding etc. or shift in requirements.
FR-G-8	High	Recurring from table B.1: The system shall enable easy modification of the decision tree and the structure (In accordance with FR-U-1 and FR-U-2).	—"—
FR-G-9	Medium	Recurring from table B.1: The system shall allow visualisation of the observations.	The collected data should be visualised in order for relevant stakeholders to take action upon the data. For instance, the observations could be visualised on a map.
Usability			
FR-U-1	High	Recurring from table B.1: The system shall support decision tree structures.	Pictorial decision trees showed promising results in similar scenarios to enable non-literate participants to collect geo-referenced points (Lewis and Nelson, 2006; Lewis, 2012b; Lewis and Nkuintchua, 2012).

Req. #	Priority	Description	Rationale
FR-U-2	High	Recurring from table B.1: The system shall support UIs with only pictorial structures, devoid of any textual or numerical information.	Multiple researchers have shown that non-literacy is a major obstacle in using mobile devices and interfaces, as virtually any standard UI contains textual and numerical elements (Chipchase, 2006; Bhamidipaty and Deepak, 2007; Joshi et al., 2008; Lalji and Good, 2008; Medhi et al., 2009; Chaudry et al., 2012; Kodagoda et al., 2012) (see section 3.2).
FR-U-3	High	Recurring from table B.1: The system shall include navigation buttons to move between the different screens of the decision tree.	Previous research supports the use of back buttons for non-literate users to navigate on pictorial decision trees (Lewis and Nelson, 2006; Lewis, 2012b; Lewis and Nkuintchua, 2012).
FR-U-4	High	Recurring from table B.1: The system shall operate in full-screen mode and hide from the user the device's status bar that displays information such as time, battery level, signal strength.	This information could confuse or distract a user.
FR-U-5	High	Recurring from table B.1: The system shall operate in loop mode where after making an observation, the user shall be presented with the home screen of the decision tree.	This would allow users to make multiple observations and prevent them from being presented with screens that include textual information such as settings screens or the system *home* screen.
FR-U-6	High	Recurring from table B.1: The system shall inform the user that an observation has been made and stored internally.	This complies with the HCI principles introduced by Nielsen (1993) (see section 4.2).

Req. #	Priority	Description	Rationale
FR-U-7	High	Recurring from table B.4: The system shall support a cancellation button that leads the user to the '*home*' screen of the decision tree.	This would allow users to quickly cancel the current observation and return to the '*home*' screen, without the need of pressing the back button multiple times.
FR-U-8	High	Recurring from table B.4: The system shall provide a confirmation screen.	This would allow users to acknowledge that they reached at the end of an observation and their action is needed to either save or discard the observation.
FR-U-9	High	Recurring from table B.4: The system shall allow optional fields.	This would allow users to skip questions without providing an answer.
FR-U-10	High	Recurring from table B.4: The system shall provide a camera UI, appropriate for non-literate participants.	An alternative, simpler and text-free version of the camera would enable non-literate participants to capture photos and provide additional evidence.
FR-U-11	High	Recurring from table B.4: The system shall prevent user from pressing the device's home button.	Whenever the '*Home*' button of the device was pressed, the user was transferred away from the data collection application to the system's main UI, which was confusing and distracting.
Security			
FR-S-1	High	Recurring from table B.1: The system shall be protected and accessible only to allowed users.	Access should be restricted since users collect points of interest that are valuable and sensitive for their local community.
FR-S-2	High	Recurring from table B.1: The system shall allow users to make observations from a safe distance.	In projects where security is an issue, for instance when users record the location of a poacher's camp, recoding from a safe distance is paramount to not risk participants' personal safety.

Req. #	Priority	Description	Rationale
Hardware			
FR-H-1	High	Recurring from table B.1: The devices shall be robust, waterproof and dustproof.	The devices should be robust enough to endure the adverse rainforest conditions, and the rough treatment that we expected our participants to have on the devices.
FR-H-2	High	Recurring from table B.1: The devices shall be equipped with GPS receivers.	In accordance with FR-G-4.
FR-H-3	High	Recurring from table B.1: The devices shall be equipped with a touch screen.	Touchscreens would enable users to interact directly with the icons displayed on the screen rather than choosing and selecting them though a keyboard which could cause confusion and difficulties to participants. In addition, physical keyboards on devices are primarily designed for English input and finding devices with a keyboard mapping to the local language could be challenging (Parikh and Lazowska, 2006).
FR-H-4	High	Recurring from table B.1: The devices shall be equipped with a camera.	In accordance with FR-G-5.
FR-H-5	High	Recurring from table B.1: The devices shall be equipped with gyroscope and compass sensors.	According to FR-S-2, the users should be allowed to make observations from a safe distance. Recording the orientation of the device could allow to meet this requirement; thus, gyroscope and compass sensors on the device are necessary.
FR-H-6	High	Recurring from table B.1: The devices shall have a battery autonomy of one week.	—

Req. #	Priority	Description	Rationale
FR-H-7	High	Recurring from table B.1: The system shall be accompanied by a charging solution appropriate for the local conditions.	Given the lack of electricity in the case study area (see section 3.2), an appropriate charging solution should be provided to ensure the feasibility of the system.
FR-H-8	Medium	Recurring from table B.1: The devices shall have removable batteries.	In cases where the devices run out of energy, spare batteries could be provided to participants and enable them to continue recoding observations.

F.2 Limitations of ODK-based prototype

As discussed in section 6.4, the first prototype was based on the open-source project ODK which is described in appendix C.1.7. However, after the first field trip and taking into account the new requirements of the project it was fairly soon obvious that ODK was unsuitable for the wider vision (see appendix B.1).

The first and most important limitation was the fact that ODK Collect was designed to be used by literate users and therefore depended heavily on textual information. As shown in figure 6.3 (page 106), ODK supported pictorial icons as part of more traditional textual forms which tend to be inappropriate and confusing for semi or non-literate participants. Hence, ODK was heavily modified to remove any numerical or textual information and cater for these user groups. The prototype version which was based on v1.2 RC1 of ODK Collect resulted in about 17% of modified code, much of which seemed like a 'hack' to hide or strip out functionality from the original application. This resulted in a difficult to maintain version. Every time ODK was updated, offering new features that may be useful for some use cases or requirements, a series of time consuming changes had to be made to keep the modified version working. For example, the ODK codebase had 233 commits in 2011 and 299 in 2012, which shows that the project was actively maintained and evolving. Additionally, our modifications to ODK were so exclusive that they couldn't be merged into the original code base of ODK. For these reasons, maintaining our own version of ODK could potentially lead to code usually referred as 'Spaghetti Code', a programming anti-pattern which makes software code unreadable (Pizka, 2004; Abbes et al., 2011).

As explained in the previous chapters, in order to overcome the literacy barrier, and since pictorial decision trees showed promising results in similar scenarios (Lewis and Nelson, 2006; Lewis and Nkuintchua, 2012), they were used in the prototype version of the Anti-Poaching project. The results of the first evaluation were encouraging, but it was realised that while in the field projects need to be easily adapted and frequently edited to reflect user's requirements and needs (FR-G-7 and FR-G-8). For instance, after discussion with participants and local collaborators, the decision tree might need to be modified. The modifications could relate to the structure of the tree, such as adding and eliminating some categories, or could require alterations for specific icons. Ideally in most of the case scenarios, this research envisioned NGO members or community representatives with basic computing skills been given the ability to make these changes such as editing and maintaining the projects without the need of a highly skilled IT person. Thus, a simple, flexible and easily comprehensible description language was required for defining and editing projects.

However, ODK's forms were based on the XForms standard (W3C, 2003, 2015), which required verbose definitions even for describing small projects. Also, the definition of decision trees was only possible with the use of constraints on the form which added even more complexity to the XForms code, as shown in appendix E. To further demonstrate the verbosity of XForms, take for example the case of a simple project containing a decision tree for a survey regarding transport modes. The project consists of a simplistic pictorial decision tree, with only two options on the root level (private and public modes of transportation), and one level underneath the root, where a selection of a specific private or public mode is possible. The project also collects a media attachment of the preferred mode (such as a photo) and the location of the observation. Figure F.1 on the left, demonstrates the verbose code needed to describe the project in XForms while on the right is the equivalent code in the Sapelli XML definition language, which will be introduced in appendix F.3.2. The full code for both examples is presented in appendix G and illustrates the difference in code needed to achieve the same structure. In projects like the described Anti-Poaching, or the participatory monitoring of logging introduced in the next chapter, the length of the ODK forms quickly becomes hard to maintain, comprehend and change when needed.

Finally, another important constraint was the complicated and verbose output produced by ODK for the collected observations. After the initial evaluation, it was concluded that in remote areas such as the rainforest, one of the most appropriate methods of quickly transferring information was via SMS messages (Lewis, 2012a). The payload of a single SMS is 140 Bytes, while the output of a single observation by ODK was at least 500 Bytes. Hence, at least 4 SMS messages were required to transmit a single observation. This was not optimal from an economic perspective but also not appropriate given the local conditions and taking into account the sparse

```xml
<?xml version="1.0"?>
<h:html xmlns="http://www.w3.org/2002/xforms" xmlns:ev="http://www.w3.org/2001/xml-events" xmlns:h="http://www.w3.org/1999/xhtml" xmlns:jr="http://openrosa.org/javarosa"
xmlns:orx="http://openrosa.org/xforms/" xmlns:xsd="http://www.w3.org/2001/XMLSchema">
    <h:head>
        <h:title>TransportationExampleODK</h:title>
        <model>
            <itext>
                <translation default="true()" lang="default">
                    <text id="/TransportationExampleODK/pressed_public/bus:label">
                        <value form="image">jr://images/bus.png</value>
                        <value>bus</value>
                    </text>
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                        <value>walking</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_private/motorised:label">
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                        <value>motorised</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_private/unmotorised:label">
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                        <value>unmotorised</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_public/subway:label">
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                        <value>subway</value>
                    </text>
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                        <value>tram</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_motorised/car:label">
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                        <value>car</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_unmotorised/skateboard:label">
                        <value form="image">jr://images/skateboard.png</value>
                        <value>skateboard</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_public/train:label">
                        <value form="image">jr://images/train.png</value>
                        <value>train</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_home/private:label">
                        <value form="image">jr://images/private.png</value>
                        <value>private</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_motorised/motorcycle:label">
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                        <value>motorcycle</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_home/public:label">
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                        <value>public</value>
                    </text>
                    <text id="/TransportationExampleODK/pressed_unmotorised/bicycle:label">
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                        <value>bicycle</value>
                    </text>
                </translation>
            </itext>
            <instance>
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                    <end/>
                    <today/>
                    <deviceid/>
                    <subscriberid/>
                    <simid/>
                    <phonenumber/>
                    <pressed_home/>
                    <pressed_private/>
                    <pressed_public/>
                    <pressed_motorised/>
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                </TransportationExampleODK>
            </instance>
            <bind jr:preload="timestamp" jr:preloadParams="start" nodeset="/TransportationExampleODK/start" type="dateTime"/>
            <bind jr:preload="timestamp" jr:preloadParams="end" nodeset="/TransportationExampleODK/end" type="dateTime"/>
            <bind jr:preload="date" jr:preloadParams="today" nodeset="/TransportationExampleODK/today" type="date"/>
            <bind jr:preload="property" jr:preloadParams="deviceid" nodeset="/TransportationExampleODK/deviceid" type="string"/>
            <bind jr:preload="property" jr:preloadParams="subscriberid" nodeset="/TransportationExampleODK/subscriberid" type="string"/>
            <bind jr:preload="property" jr:preloadParams="simserial" nodeset="/TransportationExampleODK/simid" type="string"/>
            <bind jr:preload="property" jr:preloadParams="phonenumber" nodeset="/TransportationExampleODK/phonenumber" type="string"/>
            <bind nodeset="/TransportationExampleODK/pressed_home" required="true()" type="select1"/>
            <bind nodeset="/TransportationExampleODK/pressed_private" relevant=" /TransportationExampleODK/pressed_home  = &quot;private&quot;" required="true()" type="select1"/>
            <bind nodeset="/TransportationExampleODK/pressed_public" relevant=" /TransportationExampleODK/pressed_home  = &quot;public&quot;" required="true()" type="select1"/>
            <bind nodeset="/TransportationExampleODK/pressed_motorised" relevant=" /TransportationExampleODK/pressed_private  = &quot;motorised&quot;" required="true()" type="select1"/>
            <bind nodeset="/TransportationExampleODK/pressed_unmotorised" relevant=" /TransportationExampleODK/pressed_private  = &quot;unmotorised&quot;" required="true()" type="select1"/>
            <bind nodeset="/TransportationExampleODK/pressed_car" relevant=" /TransportationExampleODK/pressed_motorised  = &quot;car&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_motorcycle" relevant=" /TransportationExampleODK/pressed_motorised  = &quot;motorcycle&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_bicycle" relevant=" /TransportationExampleODK/pressed_unmotorised  = &quot;bicycle&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_skateboard" relevant=" /TransportationExampleODK/pressed_unmotorised  = &quot;skateboard&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_walking" relevant=" /TransportationExampleODK/pressed_unmotorised  = &quot;walking&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_bus" relevant=" /TransportationExampleODK/pressed_public  = &quot;bus&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_tram" relevant=" /TransportationExampleODK/pressed_public  = &quot;tram&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_subway" relevant=" /TransportationExampleODK/pressed_public  = &quot;subway&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_train" relevant=" /TransportationExampleODK/pressed_public  = &quot;train&quot;" required="true()" type="geopoint"/>
            <bind nodeset="/TransportationExampleODK/pressed_photo" required="true()" type="binary"/>
            <bind calculate="concat('uuid:', uuid())" nodeset="/TransportationExampleODK/meta/instanceID" readonly="true()" type="string"/>
        </model>
    </h:head>
    <h:body>
        <select1 appearance="quickcompact-2" ref="/TransportationExampleODK/pressed_home">
            <label>Home Grid</label>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_home/private:label')"/>
                <value>private</value>
            </item>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_home/public:label')"/>
                <value>public</value>
            </item>
        </select1>
        <select1 appearance="quickcompact-2" ref="/TransportationExampleODK/pressed_private">
            <label>Private</label>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_private/motorised:label')"/>
                <value>motorised</value>
            </item>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_private/unmotorised:label')"/>
                <value>unmotorised</value>
            </item>
        </select1>
        <select1 appearance="quickcompact-2" ref="/TransportationExampleODK/pressed_public">
            <label>Public</label>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_public/bus:label')"/>
                <value>bus</value>
            </item>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_public/tram:label')"/>
                <value>tram</value>
            </item>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_public/subway:label')"/>
                <value>subway</value>
            </item>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_public/train:label')"/>
                <value>train</value>
            </item>
        </select1>
        <select1 appearance="quickcompact-1" ref="/TransportationExampleODK/pressed_motorised">
            <label>Motorised</label>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_motorised/car:label')"/>
                <value>car</value>
            </item>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_motorised/motorcycle:label')"/>
                <value>motorcycle</value>
            </item>
        </select1>
        <select1 appearance="quickcompact-1" ref="/TransportationExampleODK/pressed_unmotorised">
            <label>Unmotorised</label>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_unmotorised/bicycle:label')"/>
                <value>bicycle</value>
            </item>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_unmotorised/skateboard:label')"/>
                <value>skateboard</value>
            </item>
            <item>
                <label ref="jr:itext('/TransportationExampleODK/pressed_unmotorised/walking:label')"/>
                <value>walking</value>
            </item>
        </select1>
        <input ref="/TransportationExampleODK/pressed_car">
            <label>Car</label>
        </input>
        <input ref="/TransportationExampleODK/pressed_motorcycle">
            <label>Motorcycle</label>
        </input>
        <input ref="/TransportationExampleODK/pressed_bicycle">
            <label>Bicycle</label>
        </input>
        <input ref="/TransportationExampleODK/pressed_skateboard">
            <label>Skateboard</label>
        </input>
        <input ref="/TransportationExampleODK/pressed_walking">
            <label>Walking</label>
        </input>
        <input ref="/TransportationExampleODK/pressed_bus">
            <label>Bus</label>
        </input>
        <input ref="/TransportationExampleODK/pressed_tram">
            <label>Tram</label>
        </input>
        <input ref="/TransportationExampleODK/pressed_subway">
            <label>Subway</label>
        </input>
        <input ref="/TransportationExampleODK/pressed_train">
            <label>Train</label>
        </input>
        <upload mediatype="image/*" ref="/TransportationExampleODK/pressed_photo">
            <label>Photo</label>
            <hint>Photo</hint>
        </upload>
    </h:body>
</h:html>
```

ODK XForms

```xml
<?xml version="1.0" encoding="UTF-8"?>
<SapelliCollectorProject id="1234" name="TransportExampleSapelli" version="1.0">
   <Form id="TransportSurvey">
      <Choice id="TransportMode" cols="1">
         <Choice img="private.svg">
            <Choice img="motorised.svg" rows="2">
               <Choice img="car.svg" value="Car"/>
               <Choice img="motorcycle.svg" value="Motorcycle"/>
            </Choice>
            <Choice img="unmotorised.svg" rows="3">
               <Choice img="bicycle.svg" value="Bicycle"/>
               <Choice img="skateboard.svg" value="Skateboard"/>
            <Choice img="walking.svg" value="Walking" jump="Position"/>
            </Choice>
         </Choice>
         <Choice img="public.svg" cols="2">
            <Choice img="bus.svg" value="Bus"/>
            <Choice img="tram.svg" value="Tram"/>
            <Choice img="subway.svg" value="Subway"/>
            <Choice img="train.svg" value="Train"/>
         </Choice>
      </Choice>
      <Photo id="Picture" max="1"/>
      <Location id="Position" type="GPS" timeout="120"/>
      <Choice id="Confirmation" noColumn="true">
         <Choice img="ok.svg" jump="_LOOPFORM"/>
         <Choice img="cancel.svg" jump="_CANCEL"/>
      </Choice>
   </Form>
</SapelliCollectorProject>
```

Sapelli XML

Figure F.1.: Example of XForms compared to the Sapelli XML form definition.

mobile network. Table F.2 demonstrates and example of a device transmitting 1, 10, 100 and 1,000 observations to a national and an international number respectively (in case that the NGO is not based on the same country as the communities who conduct the data collection).

Table F.2.: SMS cost per device.

	National SMS	International SMS
Cost per SMS	£0.03	£0.10
1 observation	£0.12	£0.40
10 observations	£1.20	£4.00
100 observations	£12.00	£40.00
1,000 observations	£120.00	£400.00

F.3 Sapelli Development

After the development of the first ODK-based prototype, Dr Matthias Stevens joined ExCiteS as a postdoctoral fellow, collaborating closely with me on tackling the technological challenges of the project. Later, in October of 2012, Julia Altenbuchner joined the research team as a PhD student and this gave us the manpower to undertake the implementation of a new system from scratch. The following section describes the joint effort of Dr Matthias Stevens, Julia Altenbuchner and myself to develop a new data collection platform. In appendix F.3.1, I describe the contribution of each researcher on the development of the platform.

As discussed in chapter 6, the hardware selected in that case study delivered promising results and hope for the feasibility of similar case studies. However, due to the absence of an existing solution to meet the identified requirements (table F.1), in late 2012 the design and implementation of a new data collection and transmission platform was decided that would be deployed on the same hardware as in the previous case study. The reasoning for developing something new was the full control it could give over the code and thus allowing the implementation of innovative features that did not exist in other platforms. Also, if the development was done within the research group, it could allow the prioritisation of features that were more important for the existing projects rather than depending on other entities to approve and implement features based on our needs.

The resulting system was named *Sapelli* after the endangered rainforest tree (*Entandrophragma cylindricum*) which is culturally important for the forest communities in the Congo Basin. Sapelli trees are a major point of conflict amongst local forest-communities and loggers, as the trees are highly valued by loggers as a source of lucrative timber, but are also precious for the locals, for whom Sapelli is a source of delicious caterpillars especially during the early rain season (Lewis, 2002, p. 86).

Figure F.2 shows the overall architecture of the platform, which consisted of 4 main components:

- ***Sapelli Collector:*** a data collection app, with integrated data sending service for Android devices (described in appendix F.3.2);
- ***Sapelli Relay:*** an Android app designed to receive and forward SMS messages (described in appendix F.3.3);
- ***Sapelli Server:*** a web server application to receive and store data (described in appendix F.3.3); and
- ***Sapelli Launcher:*** an Android *home* replacement that provides a text-free app launching interface (described in appendix F.3.4).

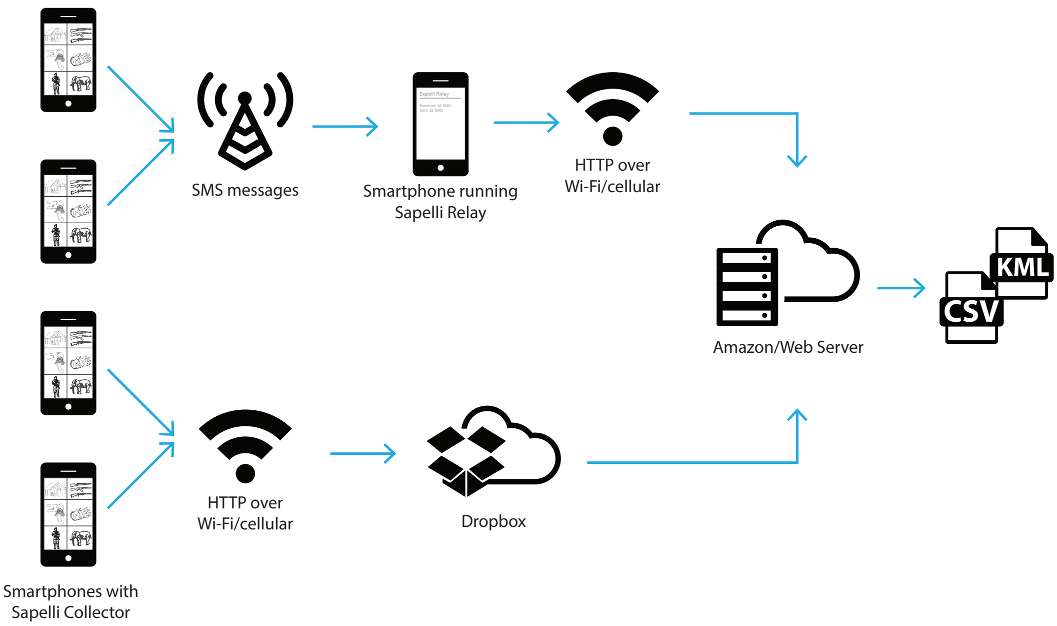


Figure F.2.: Sapelli Platform Architecture.

The suite was developed in the Java language and some parts were designed to use a common *Sapelli library*, while other parts were designed to use the Android SDK (Android, 2015a) (figure F.4). To promote code re-usability and robustness, the *Library* was written in pure Java code without any reference to frameworks (i.e. Android framework), so that it could be ported and utilised in different devices that support the Java virtual machine (JVM)[1]. For instance, figure F.4 shows that both the *Collector* and the *Server* were designed to utilise the *Library* to record, access, store and handle data records, while both the *Collector* and the *Relay* applications were designed to be compatible with Android devices running version 2.3 and upwards. For storing and retrieving information, both *Collector* and the *Server* relied on db4o, an open source, object database where information is stored in terms of objects as used in object-oriented programming rather than using relational databases (Versant Corp., 2015). An object database was preferred over traditional SQL-based databases because it offered a fast and efficient storage layer for the existing object-oriented model of Sapelli, while an relational database would require a translation of the model and would delay the implementation of the platform. The *Relay*, on the other hand, used a SQL database engine supported by Android which is named *SQLite*[2] to store and retrieve SMS messages. Finally, figure F.3 shows the lines of code and documentation that were written in order to implement the first version of the Sapelli platform[3]. As a reference point, figure F.3 also shows the lines of code in the ODK Collect codebase at that moment. The effort put on the Sapelli platform is reflected by the fact that ODK Collect has been active for more than 4 years by that point and it had 6 active developers according to the GitHub stats.

Sapelli has been released under an open-source licence and the entire source code can be retrieved from GitHub[4]. Furthermore, we have created and maintain a website with instructions on how to use and modify Sapelli, along with tutorials for first time project managers, and on how to design and deploy Sapelli projects[5]. This meets requirement FR-G-3.

F.3.1 Platform contributions

Although it is hard to clearly distinguish the contribution of each party on the development of the system, since it was a collaborative effort that no single person could achieve otherwise, we all had different research focus and priorities while developing Sapelli. Matthias Stevens comes from a Computer Science background and his focus was on creating a robust, generic system, optimised for speed and efficiency. Julia Altenbuchner's background is in GIS and Computer Science and her focus was on visual representation and effective methods of feeding back the collected data to the communities. My own background in Computer Science, led to personal contribution in the design and implementation of the Sapelli platform on

[1] An abstract machine that enables an OS to run a Java program.
[2] https://www.sqlite.org
[3] The number of code lines was calculated by the open source project *cloc*, accessed from https://github.com/AlDanial/cloc
[4] https://github.com/ExCiteS/Sapelli
[5] http://www.sapelli.org

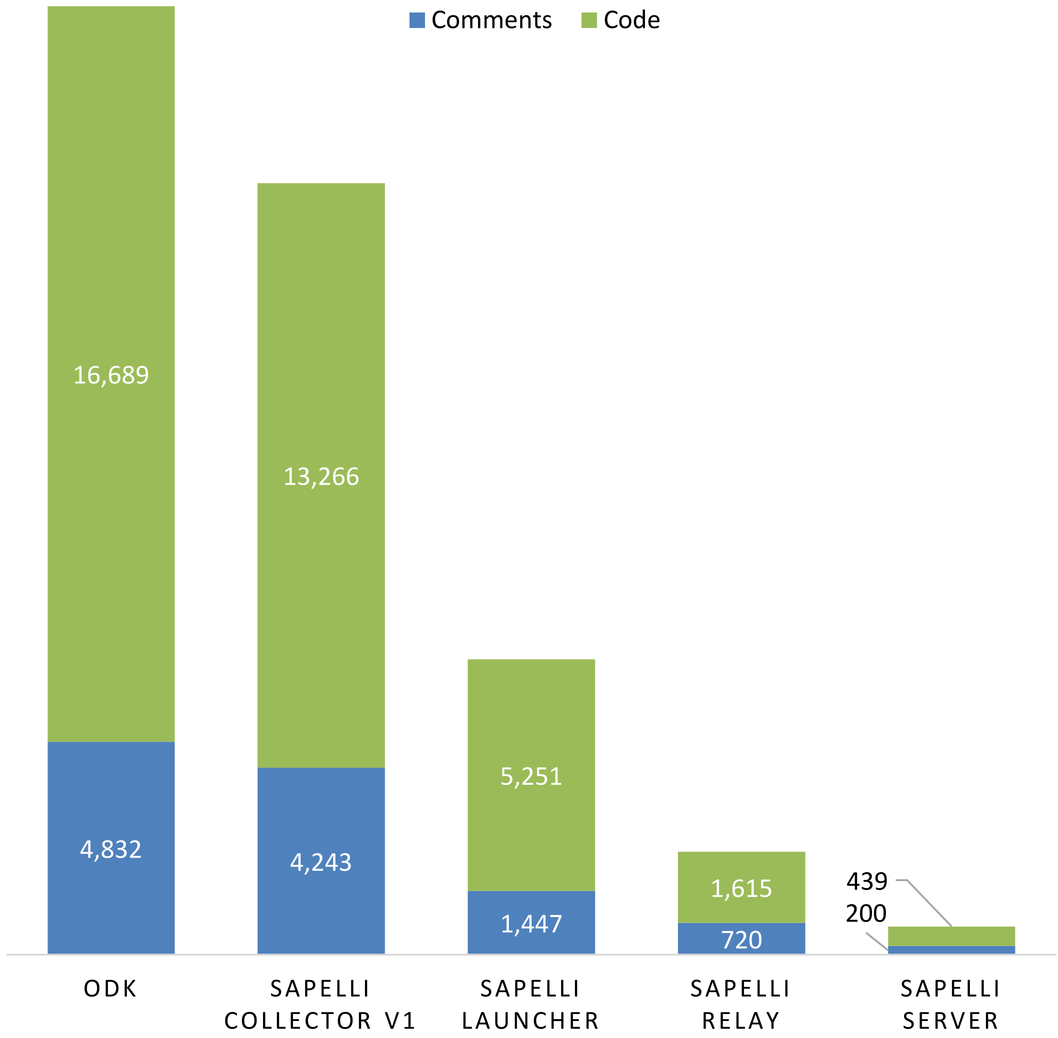


Figure F.3.: Lines of code for Sapelli platform as of May 2013.

one hand, and in the research of the usability and HCI aspects of the platform on the other.

A very common method to measure code contribution and productivity is by counting lines of code, since it is easy to measure (Rawat et al., 2012). However, this does not take at all in account the effort of **planning**, **discussing**, **designing**, **debugging**, **documenting**, **testing** and **refactoring** a codebase. As Bill Gates stated (Rawat et al., 2012), '*Measuring software productivity by lines of code is like measuring progress on an airplane by how much it weighs.*' However, since it is the only quantitative method to measure code contribution, in table F.3, I present the 4 main components of Sapelli, as shown in the previous section, and the code contribution of each researcher[6].

[6]The stats were generated by the open source project *gitinspector*, accessed from https://github.com/ejwa/gitinspector

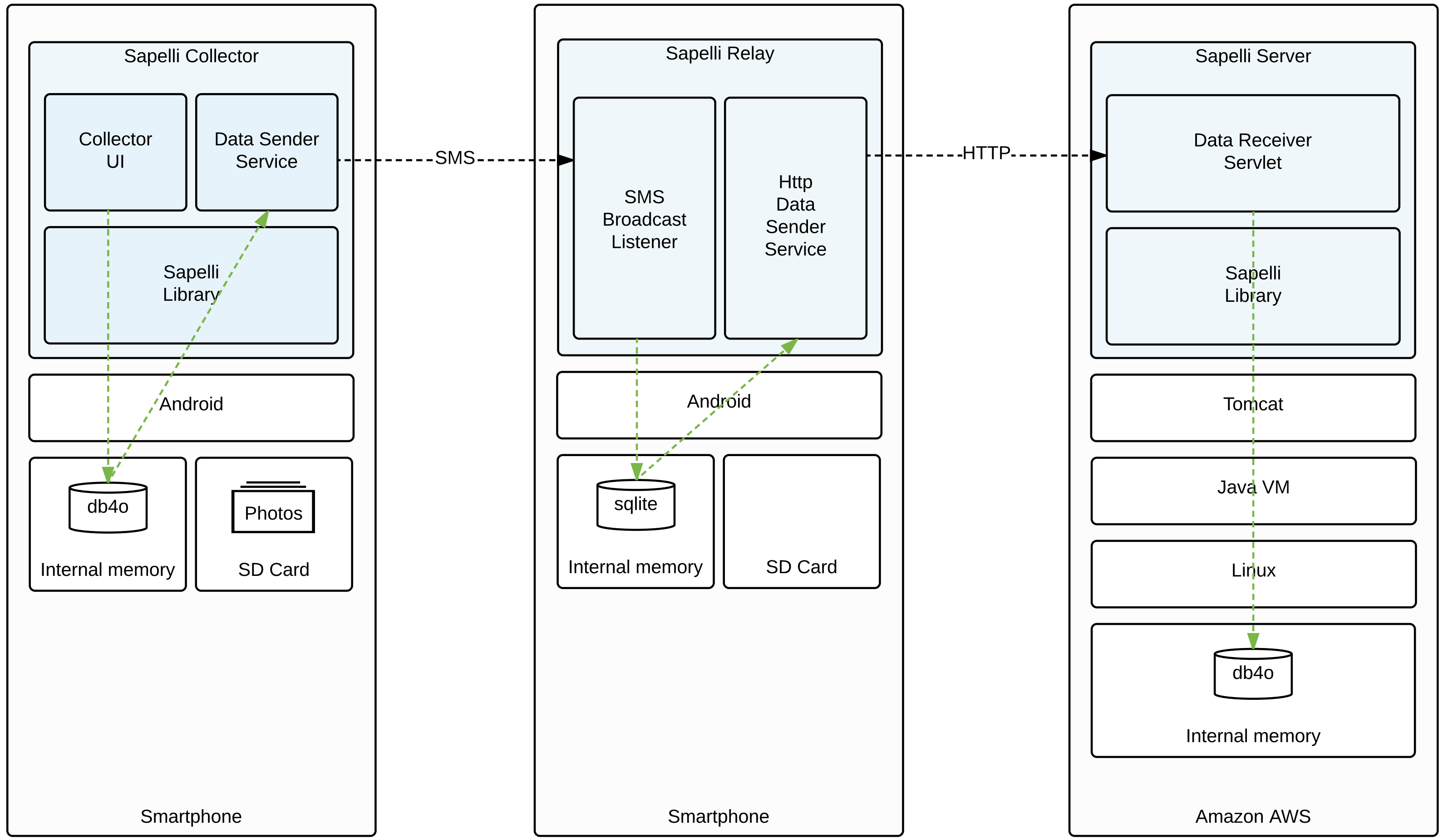


Figure F.4.: Sapelli code overview.

Table F.3.: Sapelli code contribution.

Sapelli Collector	
Julia Altenbuchner	4%
Matthias Stevens	69%
Michalis Vitos	27%
Sapelli Relay	
Michalis Vitos	100%
Sapelli Server	
Matthias Stevens	43%
Michalis Vitos	57%
Sapelli Launcher	
Michalis Vitos	100%

Note. Researchers are listed in alphabetical order based on the surname.

F.3.2 Sapelli Collector

The *Sapelli Collector v1* is the Android app of the Sapelli platform that enables data collection through pictorial only interfaces. This section shows on the Sapelli XML language used to describe the projects and lists the different tags. Finally, the XML and Comma Separated Values (CSV) export of the platform is described.

Survey elements and design

The Sapelli platform was designed to give project managers powerful tools with which to collect data, while making as few assumptions as possible about how these tools were to be used. Because of this, Sapelli data collection projects are created by declaring which features are to be used within an XML file, using terms specific to Sapelli (FR-G-7 and FR-G-8).

Due to the focus on low and non-literate users the initial priority was to facilitate the building of pictorial decision trees and icon-driven interfaces in general. Consequently, unlike most of the platforms reviewed in chapter 6 and appendix C, support for conventional textual forms such as text fields, drop-downs, radio buttons was not provided, although this was added in the second version of the platform (chapter 8).

As explained in the previous sections the inadequacy of the survey description languages used in other platforms (e.g. the XForms-derived format used in ODK) led to the design of a new XML-based format. *Sapelli XML* provides a set of predefined building blocks called fields (e.g. `<Choice>`, `<Audio>`, `<Photo>`, `<Location>` etc.) to describe surveys consisting of one or more forms (table F.4). As evident from the previous evaluation (chapter 6), data collection projects in this context called for a rapid, in-situ adaptation of data collection interfaces. Hence, we have kept the format as simple and concise as possible. Ideally modest computing skills should suffice to learn quickly how to create and update surveys (FR-G-7 and FR-G-8).

Table F.4.: Sapelli XML Tags.

Tags	Description
`<Project>`	A project element is a container for all other Sapelli elements i.e. `<Configuration>` and `<Form>`.
`<Configuration>`	A Configuration is a container for the project settings.
`<Form>`	A Form is a container for all data collection elements .
`<Choice>`	Provide a pictorial decision tree choice.
`<Audio>`	Provide a UI to capture audio records.
`<Photo>`	Provide a UI to capture photos.
`<Location>`	Captures the device's location.
`<Orientation>`	Captures the device's orientation.

As an example, figure F.5 shows how a simple pictorial survey, in this case about modes of transport in London, is described using Sapelli XML and how it appears on the screen (the full code of the example is listed in appendix G). The resulting project allows participants to initially select either private or public transportation. Depending on the initial choice, the next UI contains either motorised and unmotorised means of transportation or the options of bus, tram, subway and train respectively.

Sapelli was designed with the intention that project designers could use the platform to collect a wide range of data types, from simple pieces of text to geographical locations, photos and audio recordings. When the project creator designs the series of interfaces to be displayed to the user, he is simultaneously designing the internal model of the data they are collecting. The interfaces are grouped into forms, with

```xml
<?xml version="1.0" encoding="UTF-8"?>
<SapelliCollectorProject id="1234" name="TransportExampleSapelli" version="1.0">
  <Form id="TransportSurvey">

      <Choice id="TransportMode" cols="1">
        <Choice img="private.svg">
          <Choice img="motorised.svg" rows="3">
            <Choice img="car.svg" value="Car"/>
            <Choice img="motorcycle.svg" value="Motorcycle"/>
            <Choice img="scooter.svg" value="Scooter"/>
          </Choice>
          <Choice img="unmotorised.svg" rows="3">
            <Choice img="bicycle.svg" value="Bicycle"/>
            <Choice img="skateboard.svg" value="Skateboard"/>
            <Choice img="walking.svg" value="Walking" jump="Position"/>
          </Choice>
        </Choice>
        <Choice img="public.svg" cols="2">
          <Choice img="bus.svg" value="Bus"/>
          <Choice img="tram.svg" value="Tram"/>
          <Choice img="subway.svg" value="Subway"/>
          <Choice img="train.svg" value="Train"/>
        </Choice>
      </Choice>

      <Photo id="Picture" max="1"/>

      <Location id="Position" type="GPS" timeout="120"/>

      <Choice id="Confirmation" noColumn="true">
         <Choice img="ok.svg" jump="_LOOPFORM"/>
         <Choice img="cancel.svg" jump="_CANCEL"/>
      </Choice>

  </Form>
</SapelliCollectorProject>
```

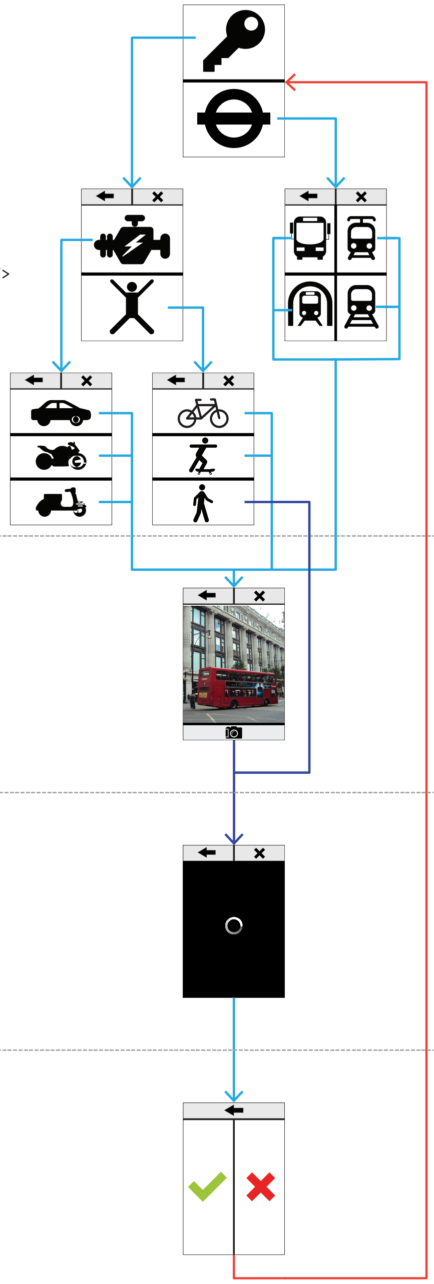


Figure F.5.: Sapelli XML example of a survey about transport modes. *Tree Icons © Flat Icon; Underground logo © TfL; Bus photo © Michalis Vitos, ExCiteS group*

each project holding one or more forms that have related purposes. Each form defines a database table within the data model (or schema), while each field in a form corresponds to a column within that form's table into which values can be entered. For example, including a Photo field in a form leaves a gap in that form's table for a photograph to be included as part of the record that the user submits. In addition to the fields declared in the XML, a timestamp and device identification columns are automatically added to the table.

All top-level fields are directly contained within the <Form> (see figure F.5) and must carry an '*id*' attribute which is used as the name of column where values for the field will be stored and transmitted. Optionally, fields can also contain a '*jump*' attribute. This reference mechanism is primarily intended for control flow across fields. The jump attribute indicates which field (referred to by its id) the user should be taken to next. If no jump attribute is given, the lexical order of fields is respected (e.g. in the example, in figure F.5, the '*position*' field will be followed by the '*confirmation*' field).

To summarise:

- A project contains one or more forms which contain one or more fields.
- A model contains one or more tables which contain one or more columns.
- By declaring a project, the project creator declares a model.
- By declaring a form in a project, the project creator declares a new table in that model.
- By declaring a field in a form, the project creator declares a new column in that table.
- A timestamp and device identification columns are automatically added to the table.
- A field provides the user with an interface to submit a piece of data for a particular column.
- A record is a set of values for each column in a particular table.
- Jump attributes can be used to control flow across fields.
- If no jump is given, a lexical order of fields is followed.

The first version of Sapelli, provided a set of 5 predefined building blocks: `<Choice>`, `<Audio>`, `<Photo>`, `<Location>`, `<Orientation>` (table F.4).

<Choice> field: A <Choice> field presents the user with a series of pictorial choices (FR-U-2). A single <Choice> item can represent both a question and an answer, and the project designer must create a '*decision tree*' of nested <Choice> nodes in order to collect the answer to a single question.

Decision trees or conditional constructs in general, are built by nesting <Choice> nodes (FR-U-1). The outermost <Choice> item represents the first decision that must be made. This hierarchic description makes the structure of the decision space (i.e. the tree) immediately apparent by looking at the code, provided that proper indentation is used (see for instance figure F.5). It is worth noting that the majority of text editors that support XML, automatically provide such an indentation. Figure F.6 shows how the outer <Choice> element represents *motorised* modes of transportation and then each inner <Choice> is translated into an icon on the device's screen.

```
<Choice img="motorised.svg" rows="3">

  <Choice img="car.svg" value="Car"/>

  <Choice img="motorcycle.svg" value="Motorcycle"/>

  <Choice img="scooter.svg" value="Scooter"/>
</Choice>
```

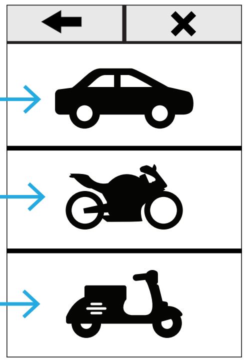


Figure F.6.: Sapelli XML detail of transport modes form.

Users navigate the decision space by repeatedly selecting a child node until they reach a leaf node, which represents a final selected value. This hierarchical approach was chosen because, in terms of graph theory, it is expected that in the majority of projects it should be feasible[7] to describe the decision space as a tree rather than a graph. Graphs can be constructed by using the jump mechanism to jump to another branch of the same decision tree. This is supported as long as no cycles are created. In such a case the decision space effectively becomes a directed acyclic graph.

An alternative linear approach would necessitate a reference mechanism to link parent and child nodes, requiring survey designers to invent and remember many more ids and leading to a more verbose description.

In the case of nested <Choice> elements, nodes without a jump attribute inherit that of their parent. This makes it easy to vary control flow in function of the choices

[7]And desirable, to avoid confusing users.

made by the user. For instance, in the transportation example after selecting '*Walking*' as his/her mode of transport the user will not be given the option to take a photo because, unlike selecting one of the other options, the '*picture*' will be skipped and instead the user will be presented with the '*position*' UI (figure F.5).

`<Choice>` constructs can also be used in cases where the only goal is control flow, rather than modelling the survey decision space. This is demonstrated by the '*confirmation*' field in the example, which asks users to confirm their form entry for it is saved (figure F.5). The '*noColumn*' attribute indicates that this field does not itself store data.

Finally, it is interesting to note that `<Choice>` constructs can also be used to build decision-making charts, which not only allow users to express an observation using the system, but also allow the system to help them learn things about what they are observing. Dichotomous key diagrams, used by biologists to identify specimens, are a good example.

<Audio> field: An `<Audio>` field is a type of *Media* field that allows for the collection of audio recordings using the device's inbuilt microphone (FR-G-5). Various optional attributes (not shown in the example) are available to specify things like the audio encoding format etc.

<Photo> field: Similarly, a `<Photo>` field is a type of *Media* field that allows for the collection of photos taken with the device's camera(s) (FR-G-5 and FR-U-10). Some of the optional attributes include the option to use the front camera of a device, enabling/disabling of the flash, etc.

<Location> field: A `<Location>` field allows the project designer to store various components of the device's location at the time this Field was reached, including latitude and longitude, altitude, bearing and speed (FR-G-4). One of the crucial configuration options of a Location field is the specification of the '*type*' or source of the location data – whether the app determines the user's location from GPS, from the network or from either. This can help reduce battery life (i.e. by disallowing GPS) or request a certain level of accuracy (by disallowing network-based locations).

Additional attributes allow the project designer to determine whether to start listening for a location as soon as the user enters the containing *Form* (as opposed to when they reach the Location field itself) and to specify a certain accuracy radius and recency through which inadequate location readings will be rejected.

<Orientation> field: Finally the <Orientation> field allows the recording of the orientation of the device in 3-dimensional space (Azimuth, Pitch and Roll) using built-in sensors (FR-S-2). As explained in the Android SDK (2015), '*Azimuth*' is the rotation around the Z axis, varying from 0° to 360°. An angle of 0° means the top of the device is pointing to magnetic North. '*Pitch*' is the rotation around the X axis, varying from -90° to 90°. An angle of 90° means that the device is pointed to the ground, -90° means it is pointed to the sky. '*Roll*' is the rotation around the Y axis, varying from -180° to 180°. An angle of 0° means that the device is lying on its back (screen facing upwards), (-)180° means it is lying on its 'face' (screen facing downwards).

Data export

Sapelli allows data to be exported in XML and CSV formats. This enables data validation and the option to import the data to more advanced tools for further analysis and manipulation, for example the CSV output could be imported to Microsoft Excel or QGIS for data analysis and spatial analysis respectively. Listing F.1 shows an example of an XML output for the transportation project that we presented in this section. The output includes the time of the record in various formats (ISO-8601, Unix etc.) so that different platforms can read it, the unique device id, the *Choice* of the decision tree and the location of the observation. Finally, listing F.2 shows the same data export as a CSV file.

Listing F.1: Sapelli XML data export

```
<?xml version="1.0" encoding="UTF-8"?>
<RecordsExport exportedAt="2016-07-02T18:04:31.968+01:00">
  <Record schemaName="Transport_Demo_(v2.3):Survey" modelID="5279027149407442"
      modelSchemaNumber="1">
    <StartTime>2016-07-02T18:01:39.901+01:00</StartTime>
    <StartTime-LocalYYYYMMDD_HHMMSS>2016-07-02 18:01:39</StartTime-
        LocalYYYYMMDD_HHMMSS>
    <StartTime-UCTOffsetH>1.0</StartTime-UCTOffsetH>
    <StartTime-UnixMS>1467478899901</StartTime-UnixMS>
    <DeviceID>4155932026</DeviceID>
    <TransportMode>5</TransportMode>
    <TransportMode-Value>Walking</TransportMode-Value>
    <TransportMode-Image>walking.svg</TransportMode-Image>
    <!-- TransportMode-Caption is null -->
    <!-- Picture is null -->
    <!-- Picture-Files is null -->
    <Position.Latitude>51.53860833333333</Position.Latitude>
    <Position.Longitude>-0.12201333333333333</Position.Longitude>
    <Position.Altitude>53.0</Position.Altitude>
    <Position.Bearing>0.0</Position.Bearing>
    <Position.Speed>0.0</Position.Speed>
    <Position.Accuracy>16.299999237060547</Position.Accuracy>
    <Position.TimeUTC>2016-07-02T18:02:06.000+01:00</Position.TimeUTC>
    <Position.Provider>1</Position.Provider>
  </Record>
</RecordsExport>
```

Listing F.2: Sapelli CSV data export

```
StartTime, StartTime-LocalYYYYMMDD_HHMMSS, StartTime-UCTOffsetH, StartTime-UnixMS,
    DeviceID, TransportMode, TransportMode-Value, TransportMode-Image,
    TransportMode-Caption, Picture, Picture-Files, Position, Position.Latitude,
    Position.Longitude, Position.Altitude, Position.Bearing, Position.Speed,
    Position.Accuracy, Position.TimeUTC, Position.Provider, LosslessFlag, modelID
    =5279027149407442, modelSchemaNumber=1, schemaName="Transport_Demo_(v2.3):
    Survey", exportedAt=2016-07-02T18:02:50.123+01:00,
2016-07-02T18:01:39.901+01:00, "2016-07-02 18:01:39", 1.0, 1467478899901,
    4155932026, 5, "Walking", "walking.svg", , , , true, 51.53860833333333,
    -0.12201333333333333, 53.0, 0.0, 0.0, 16.299999237060547, 2016-07-02T18
    :02:06.000+01:00, 1, true
```

F.3.3 Sapelli Relay: Data Synchronisation

The Sapelli platform provided an autonomous, multi-modal data transmission mechanism to submit survey entries to a central server (FR-G-6). Sapelli Collector included a background service that automatically checked for connectivity at scheduled intervals that could be changed on the applications settings (figure F.4). In order to conserve power there was an option to put the device into flight mode between checks. When there was data to be sent, and a transmission opportunity arose, the service autonomously decided what to transmit and how, depending on available networks, bandwidth and project-specific settings, declared in the XML project description.

The transmission of basic form entry data (i.e. timestamps, decision tree selections, coordinates, etc.), which required little bandwidth, happened independently of the much larger '*media attachments*' (i.e. photos, audio recordings). This was important because urgency and timeliness was a major factor in some of the projects. For instance, reports about poaching activity should not being held up because there was insufficient bandwidth to transmit the attached photos.

To transmit the basic data, records were serialised in a binary format which was heavily optimised for space. Next, these were grouped together in transmissions that could either be sent via SMS[8], or HTTP (over cellular or Wi-Fi networks). Transmission payloads were compressed to further reduce bandwidth requirements and could be encrypted for security reasons. The number of records sent via each SMS text depends on the project (i.e. the number of fields per form) and the compression algorithm applied to the records. Sapelli before initiating the SMS transmission applies a list of compression algorithms[9] to the data and finally uses the one producing the optimal results. For example, regarding the project described in chapter 7, each SMS transmission contained an average of 10 records. SMS messages were sent to another phone, running the Sapelli Relay app, which received and forwarded the messages to the server (see figure F.2 and figure F.4). The Sapelli Relay was preferably located in the same country to avoid high costs of sending multiple SMS messages to an international number and it had reliable Internet access to successfully forward the received data to the server. While the development of Sapelli was a collaborative effort, the design and implementation of the *Sapelli Relay* was a personal project under my control.

For the transmission of media attachments the Dropbox Sync API (Dropbox, 2015) was evaluated. Dropbox is a cloud storage and file synchronisation service, which enables users to sync folders and files between their connected to the Dropbox machines (personal computers, tablets, smartphones etc.) and the Dropbox cloud server[10]. The integration with the Dropbox Sync API allowed Sapelli to '*push*' media attachments, such as photos and audio recordings, to Dropbox which handled, in the background, their uploading to the Dropbox cloud server when Internet (cellular

[8]Transmissions could span up to 16 chained SMS messages.
[9]BZIP2, DEFLATE, GZIP, LZMA and LZMA2
[10]https://www.dropbox.com

or Wi-Fi) was available (see figure F.2). The uploaded media files could then be accessed and transferred to the Sapelli Server.

The filenames of the attachments were generated through a hashing algorithm that took the record timestamp and device identification as input. This allows Sapelli Server to reliably associate newly-received attachments with records received earlier, for instance via SMS messages.

The Sapelli Server component was implemented in Java and shared a significant part of its code with the Sapelli Collector application. At that stage, the server's features were limited to receiving and storing data, and generating reports in CSV. In the future, it was planned to add options for exporting the data in other formats such as XML, KML, and Shapefile etc.

F.3.4 Sapelli Launcher

A text-free application can still be difficult to use for low or non-literate participants when it runs on an operating system with a complicated, text-heavy interface such as Android. Whenever the '*Home*' button of the device is pressed, the user is transferred away from the data collection application to the system's main UI, which differs depending on the Android version of the OS and the manufacturer of the device. Different manufacturers are implementing their own personalised UI theme for Android to differentiate themselves from the competition (Mitroff, 2014). Figure F.7 shows the '*Home*' UI for three different vendors. By pressing the home button, apart from being confusing, the participant has access to settings and options that could compromise the success of the project, for instance a user could disable by accident the GPS or the Wi-Fi of the smartphone and as a result Sapelli Collector would be unable to collect GPS coordinates and transmit the collected data via internet. In addition, in Android, apps cannot enable settings such as GPS and Wi-Fi without the users' consent. In this particular case, a dialogue asking the user to enable the GPS was not applicable.

To tackle this issue, I have developed the '*Sapelli Launcher*'. An application that can be installed on any Android-based device and replace the complicated, standard Android UI with a restricted, text-free app launching interface (FR-U-11). This interface only shows icons for a set of allowed apps, which can be tailored based on project requirements and user abilities. Sapelli Collector is fully compatible with the Launcher and shortcuts that lead to specific projects instead of the main screen of the Collector app, can be created. For instance, figure F.8a is demonstrating the main screen of the Launcher containing only two icons, both shortcuts for data collection

(a) Stock UI for Android Lollipop

(b) Samsung UI for Android Lollipop

(c) HTC UI for Android Lollipop

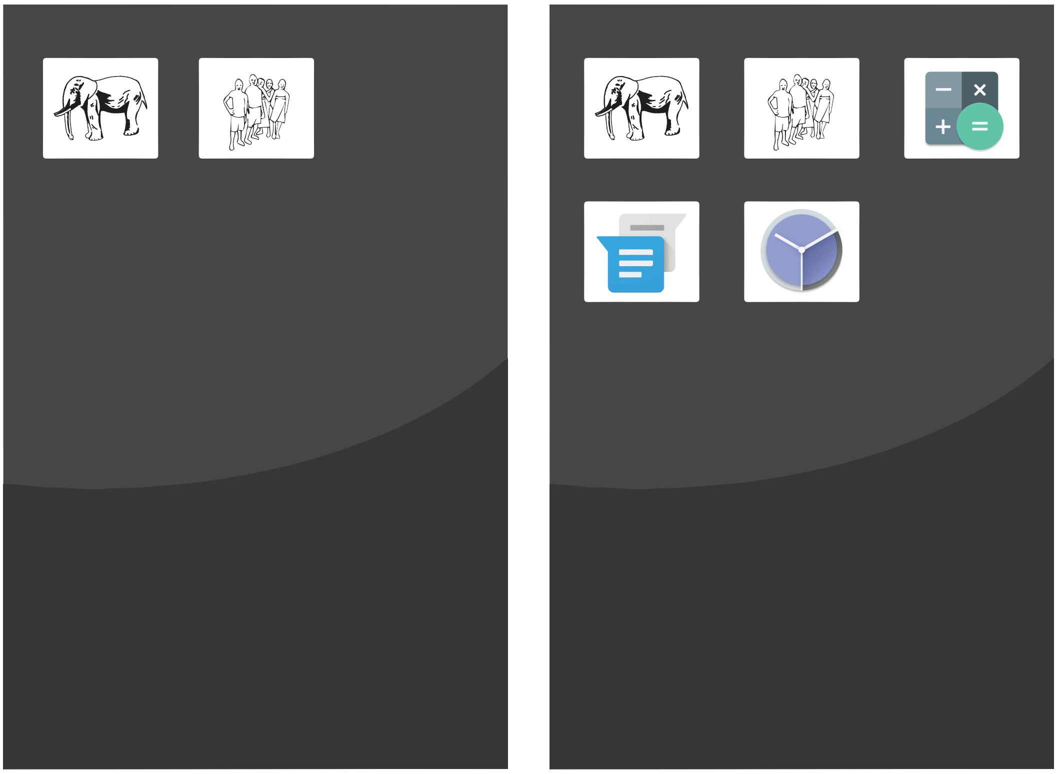
Figure F.7.: Different versions of Android's home screen. *Image a © Android; Image b © Samsung; Image c © HTC*

projects. The first icon leads to the Anti-Poaching project, described in the previous chapter, while the second icon leads to participatory monitoring of logging project.

Besides allowing access only to data collection, the Launcher can provide access to other system applications depending on the users' level of literacy or the needs of a specific project. For example, in figure F.8b, participants have also access to the calculator, to the messaging app and to the clock, along with the two Sapelli Collector projects.

In order to configure the application there was a need for a password-protected, hard to access, secret menu. This menu was presented only after a special combination of keys was pressed and then a password prompt was authenticating the users. This prevented accidental and unauthorised access to the Launcher settings. Figure F.9a, shows the hidden, settings menu, from where the project administrator could select which applications were approved to be used by the users (figure F.9b), access the system's settings – so that to enable or disable GPS, Wi-Fi, choose sound level etc., import and export the settings and finally change the password for the Sapelli Launcher application.

Finally, to prevent unauthorised access, apps could be protected with a mechanism similar to Android's pattern unlock feature specified per app (figure F.9c). Therefore, sensitive data collection projects could be pattern protected, while others could be access-free. The difference of this pattern unlock mechanism implemented into the



(a) Home screen with access to two Sapelli projects

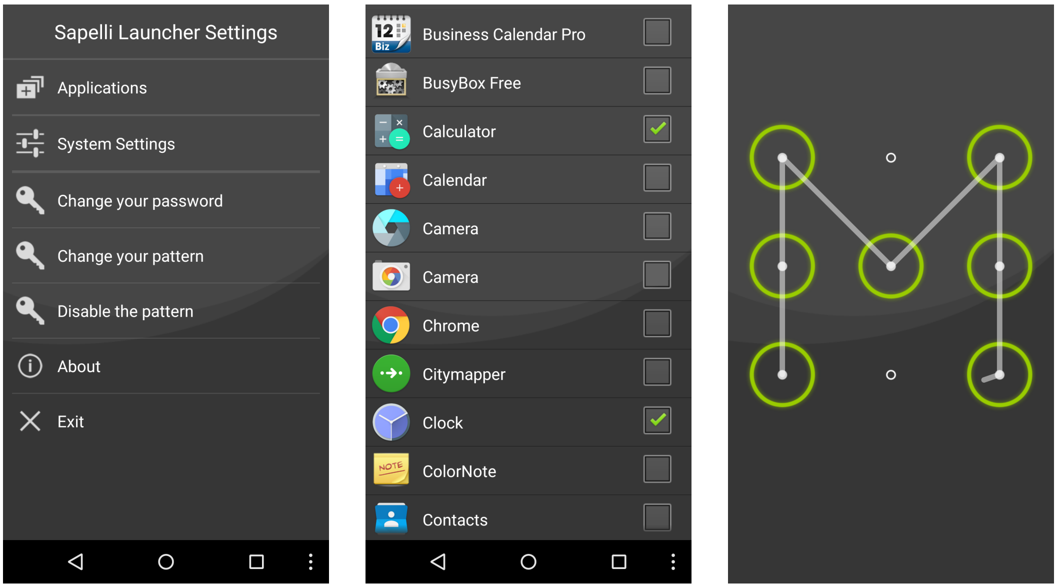
(b) Home screen with access to projects, calculator, SMS and clock

Figure F.8.: Different home screen based on the allowed applications.

Sapelli Launcher, compared to the default pattern unlock in Android was that this allowed specific apps to be protected instead of the entire device, which offered a fine-grained control.

Another advantage of Sapelli Launcher is that it can be installed on any device without requiring rooting. Rooting is a process of enabling users to gain privileged control of the device known as '*root access*'. To achieve that, rooting requires vast technological and computer expertise as it involves a different process depending on the brand and model of the device. In addition, rooting can void the device's warranty and undermine the system's security, thus it is not recommended (Höbarth and Mayrhofer, 2011; Vidas et al., 2011; Oh et al., 2012). An unsuccessful rooting could lead into '*bricking*' the equipment, a state where a device due to misconfiguration or corrupted firmware becomes unusable and useless. Finally, deploying larger-scale projects would require the rooting of numerous devices which could prove time-consuming and dangerous for the equipment. Sapelli Launcher eliminated those concerns by offering a simple method of controlling and hiding functionalities off the smartphones.

On March 2015, the release of Android Lollipop 5.1 introduced a new feature in Android named '*Screen Pinning*', which allows users to select one app and '*pin*'



(a) Sapelli Launcher settings menu

(b) Menu for selecting the approved applications

(c) Pattern protection per application

Figure F.9.: Configuring Sapelli Launcher.

it to the screen. This means that the device runs on a kiosk mode and no other functionalities can be accessed (Google, 2015b). Even with that feature, the Sapelli Launcher is a key component to the ExCiteS projects, since it allows access to multiple permitted apps and not just the one that is pinned on the screen on the one hand, and allows pattern protection on an app basis on the other. However, this is a clear indication that the functionality of the Sapelli Launcher was useful beyond our projects and Android is incorporating such functionalities on the core of the OS.

F.4 New requirements

Table F.5.: New and recurring functional requirements for Sapelli platform

Req. #	Priority	Description	Rationale
General			
FR-G-10	High	The SMS transmission mechanism should ensure the safe delivery of records.	Due to network inconsistencies it was vital to ensure that SMS messages were delivered safely. Thus there is a need for a mechanism to detect network inconsistencies, acknowledge received messages and request retransmission of missing packages.

Req. #	Priority	Description	Rationale
FR-G-11	High	The system should enable transmission of media attachments.	The effort to integrate Sapelli with the Dropbox Sync API proved unsuitable for the local network circumstances. Thus the system should be equipped with other mechanisms to upload media attachments.
Usability			
FR-U-12	High	The system shall explore alternative UIs to facilitate participants' navigation on hierarchical structures.	Participants were observed to have difficulties navigating on hierarchical structures such as the decision tree offered by Sapelli. UIs should be explored to assist participants understand the structure or offer them alternative modes for capturing data.

XForms vs Sapelli XML

G

This is a minimalist example of a project using a decision tree to survey transport modes. Listing G.1 shows the required code in *Sapelli XML*, while listing G.2 demonstrates the verbose code needed to construct the same structure using the ODK *XForms* format.

Listing G.1: Transportation Example in Sapelli XML

```
<?xml version="1.0" encoding="UTF-8"?>
<SapelliCollectorProject id="1234" name="TransportExampleSapelli" version="1.0">
  <Form id="TransportSurvey">
    <Choice id="TransportMode" cols="1">
      <Choice img="private.svg">
        <Choice img="motorised.svg" rows="3">
          <Choice img="car.svg" value="Car"/>
          <Choice img="motorcycle.svg" value="Motorcycle"/>
          <Choice img="scooter.svg" value="Scooter"/>
        </Choice>
        <Choice img="unmotorised.svg" rows="3">
          <Choice img="bicycle.svg" value="Bicycle"/>
          <Choice img="skateboard.svg" value="Skateboard"/>
          <Choice img="walking.svg" value="Walking" jump="Position"/>
        </Choice>
      </Choice>
      <Choice img="public.svg" cols="2">
        <Choice img="bus.svg" value="Bus"/>
        <Choice img="tram.svg" value="Tram"/>
        <Choice img="subway.svg" value="Subway"/>
        <Choice img="train.svg" value="Train"/>
      </Choice>
    </Choice>
    <Photo id="Picture" max="1"/>
    <Location id="Position" type="GPS" timeout="120"/>
    <Choice id="Confirmation" noColumn="true">
      <Choice img="ok.svg" jump="_LOOPFORM"/>
      <Choice img="cancel.svg" jump="_CANCEL"/>
    </Choice>
  </Form>
</SapelliCollectorProject>
```

Listing G.2: Transportation Example in XForms

```xml
<?xml version="1.0"?>
<h:html xmlns="http://www.w3.org/2002/xforms"
  xmlns:ev="http://www.w3.org/2001/xml-events"
  xmlns:h="http://www.w3.org/1999/xhtml"
  xmlns:jr="http://openrosa.org/javarosa"
  xmlns:orx="http://openrosa.org/xforms/"
  xmlns:xsd="http://www.w3.org/2001/XMLSchema">
  <h:head>
    <h:title>TransportationExampleODK</h:title>
    <model>
      <itext>
        <translation default="true()" lang="default">
          <text id="/TransportationExampleODK/pressed_public/bus:label">
            <value form="image">jr://images/bus.png</value>
            <value>bus</value>
          </text>
          <text id="/TransportationExampleODK/pressed_unmotorised/walking:label">
            <value form="image">jr://images/walking.png</value>
            <value>walking</value>
          </text>
          <text id="/TransportationExampleODK/pressed_private/motorised:label">
            <value form="image">jr://images/motorised.png</value>
            <value>motorised</value>
          </text>
          <text id="/TransportationExampleODK/pressed_private/unmotorised:label">
            <value form="image">jr://images/unmotorised.png</value>
            <value>unmotorised</value>
          </text>
          <text id="/TransportationExampleODK/pressed_public/subway:label">
            <value form="image">jr://images/subway.png</value>
            <value>subway</value>
          </text>
          <text id="/TransportationExampleODK/pressed_public/tram:label">
            <value form="image">jr://images/tram.png</value>
            <value>tram</value>
          </text>
          <text id="/TransportationExampleODK/pressed_motorised/car:label">
            <value form="image">jr://images/car.png</value>
            <value>car</value>
          </text>
          <text id="/TransportationExampleODK/pressed_unmotorised/skateboard:label">
            <value form="image">jr://images/skateboard.png</value>
            <value>skateboard</value>
          </text>
          <text id="/TransportationExampleODK/pressed_public/train:label">
            <value form="image">jr://images/train.png</value>
            <value>train</value>
          </text>
          <text id="/TransportationExampleODK/pressed_home/private:label">
            <value form="image">jr://images/private.png</value>
```

```xml
          <value>private</value>
        </text>
        <text id="/TransportationExampleODK/pressed_motorised/motorcycle:label">
          <value form="image">jr://images/motorcycle.png</value>
          <value>motorcycle</value>
        </text>
        <text id="/TransportationExampleODK/pressed_home/public:label">
          <value form="image">jr://images/public.png</value>
          <value>public</value>
        </text>
        <text id="/TransportationExampleODK/pressed_unmotorised/bicycle:label">
          <value form="image">jr://images/bicycle.png</value>
          <value>bicycle</value>
        </text>
      </translation>
    </itext>
    <instance>
      <TransportationExampleODK id="Demo">
        <start/>
        <end/>
        <today/>
        <deviceid/>
        <subscriberid/>
        <simid/>
        <phonenumber/>
        <pressed_home/>
        <pressed_private/>
        <pressed_public/>
        <pressed_motorised/>
        <pressed_unmotorised/>
        <pressed_car/>
        <pressed_motorcycle/>
        <pressed_bicycle/>
        <pressed_skateboard/>
        <pressed_walking/>
        <pressed_bus/>
        <pressed_tram/>
        <pressed_subway/>
        <pressed_train/>
        <pressed_photo/>
        <meta>
          <instanceID/>
        </meta>
      </TransportationExampleODK>
    </instance>
    <bind jr:preload="timestamp" jr:preloadParams="start" nodeset="/
        TransportationExampleODK/start" type="dateTime"/>
    <bind jr:preload="timestamp" jr:preloadParams="end" nodeset="/
        TransportationExampleODK/end" type="dateTime"/>
    <bind jr:preload="date" jr:preloadParams="today" nodeset="/
        TransportationExampleODK/today" type="date"/>
```

```
<bind jr:preload="property" jr:preloadParams="deviceid" nodeset="/TransportationExampleODK/deviceid" type="string"/>
<bind jr:preload="property" jr:preloadParams="subscriberid" nodeset="/TransportationExampleODK/subscriberid" type="string"/>
<bind jr:preload="property" jr:preloadParams="simserial" nodeset="/TransportationExampleODK/simid" type="string"/>
<bind jr:preload="property" jr:preloadParams="phonenumber" nodeset="/TransportationExampleODK/phonenumber" type="string"/>
<bind nodeset="/TransportationExampleODK/pressed_home" required="true()" type="select1"/>
<bind nodeset="/TransportationExampleODK/pressed_private" relevant=" /TransportationExampleODK/pressed_home = &quot;private&quot;" required="true()" type="select1"/>
<bind nodeset="/TransportationExampleODK/pressed_public" relevant=" /TransportationExampleODK/pressed_home = &quot;public&quot;" required="true()" type="select1"/>
<bind nodeset="/TransportationExampleODK/pressed_motorised" relevant=" /TransportationExampleODK/pressed_private = &quot;motorised&quot;" required="true()" type="select1"/>
<bind nodeset="/TransportationExampleODK/pressed_unmotorised" relevant=" /TransportationExampleODK/pressed_private = &quot;unmotorised&quot;" required="true()" type="select1"/>
<bind nodeset="/TransportationExampleODK/pressed_car" relevant=" /TransportationExampleODK/pressed_motorised = &quot;car&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_motorcycle" relevant=" /TransportationExampleODK/pressed_motorised = &quot;motorcycle&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_bicycle" relevant=" /TransportationExampleODK/pressed_unmotorised = &quot;bicycle&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_skateboard" relevant=" /TransportationExampleODK/pressed_unmotorised = &quot;skateboard&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_walking" relevant=" /TransportationExampleODK/pressed_unmotorised = &quot;walking&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_bus" relevant=" /TransportationExampleODK/pressed_public = &quot;bus&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_tram" relevant=" /TransportationExampleODK/pressed_public = &quot;tram&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_subway" relevant=" /TransportationExampleODK/pressed_public = &quot;subway&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_train" relevant=" /TransportationExampleODK/pressed_public = &quot;train&quot;" required="true()" type="geopoint"/>
<bind nodeset="/TransportationExampleODK/pressed_photo" required="true()" type="binary"/>
```

```xml
    <bind calculate="concat('uuid:', uuid())" nodeset="/TransportationExampleODK/meta/instanceID" readonly="true()" type="string"/>
  </model>
</h:head>
<h:body>
  <select1 appearance="quickcompact-2" ref="/TransportationExampleODK/pressed_home">
    <label>Home Grid</label>
    <item>
      <label ref="jr:itext('/TransportationExampleODK/pressed_home/private:label')"/>
      <value>private</value>
    </item>
    <item>
      <label ref="jr:itext('/TransportationExampleODK/pressed_home/public:label')"/>
      <value>public</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-2" ref="/TransportationExampleODK/pressed_private">
    <label>Private</label>
    <item>
      <label ref="jr:itext('/TransportationExampleODK/pressed_private/motorised:label')"/>
      <value>motorised</value>
    </item>
    <item>
      <label ref="jr:itext('/TransportationExampleODK/pressed_private/unmotorised:label')"/>
      <value>unmotorised</value>
    </item>
  </select1>
  <select1 appearance="quickcompact-2" ref="/TransportationExampleODK/pressed_public">
    <label>Public</label>
    <item>
      <label ref="jr:itext('/TransportationExampleODK/pressed_public/bus:label')"/>
      <value>bus</value>
    </item>
    <item>
      <label ref="jr:itext('/TransportationExampleODK/pressed_public/tram:label')"/>
      <value>tram</value>
    </item>
    <item>
      <label ref="jr:itext('/TransportationExampleODK/pressed_public/subway:label')"/>
      <value>subway</value>
    </item>
```

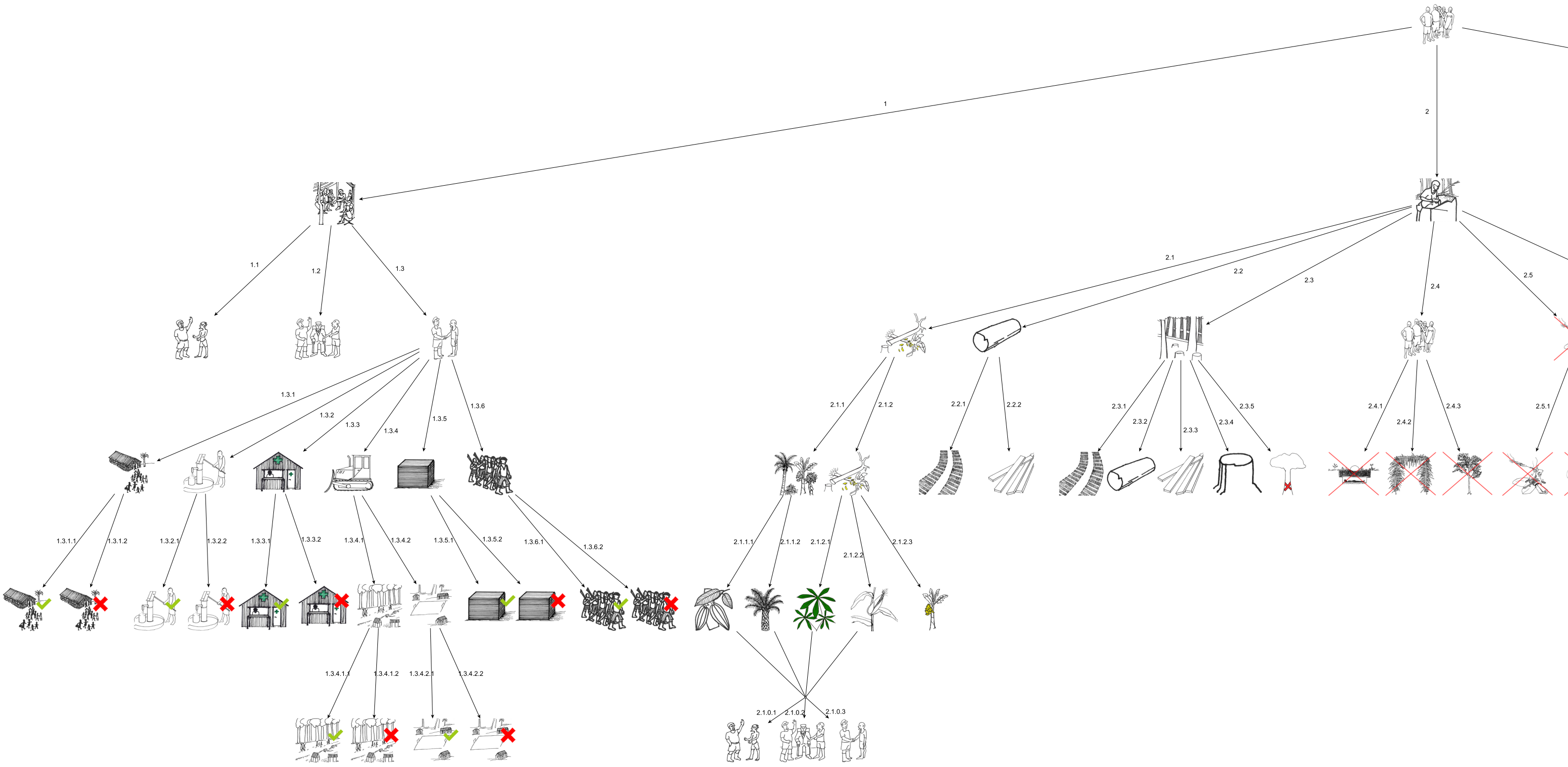
```
      <item>
        <label ref="jr:itext('/TransportationExampleODK/pressed_public/train:label')"/>
        <value>train</value>
      </item>
    </select1>
    <select1 appearance="quickcompact-1" ref="/TransportationExampleODK/pressed_motorised">
      <label>Motorised</label>
      <item>
        <label ref="jr:itext('/TransportationExampleODK/pressed_motorised/car:label')"/>
        <value>car</value>
      </item>
      <item>
        <label ref="jr:itext('/TransportationExampleODK/pressed_motorised/motorcycle:label')"/>
        <value>motorcycle</value>
      </item>
    </select1>
    <select1 appearance="quickcompact-1" ref="/TransportationExampleODK/pressed_unmotorised">
      <label>Unmotorised</label>
      <item>
        <label ref="jr:itext('/TransportationExampleODK/pressed_unmotorised/bicycle:label')"/>
        <value>bicycle</value>
      </item>
      <item>
        <label ref="jr:itext('/TransportationExampleODK/pressed_unmotorised/skateboard:label')"/>
        <value>skateboard</value>
      </item>
      <item>
        <label ref="jr:itext('/TransportationExampleODK/pressed_unmotorised/walking:label')"/>
        <value>walking</value>
      </item>
    </select1>
    <input ref="/TransportationExampleODK/pressed_car">
      <label>Car</label>
    </input>
    <input ref="/TransportationExampleODK/pressed_motorcycle">
      <label>Motorcycle</label>
    </input>
    <input ref="/TransportationExampleODK/pressed_bicycle">
      <label>Bicycle</label>
    </input>
    <input ref="/TransportationExampleODK/pressed_skateboard">
      <label>Skateboard</label>
    </input>
```

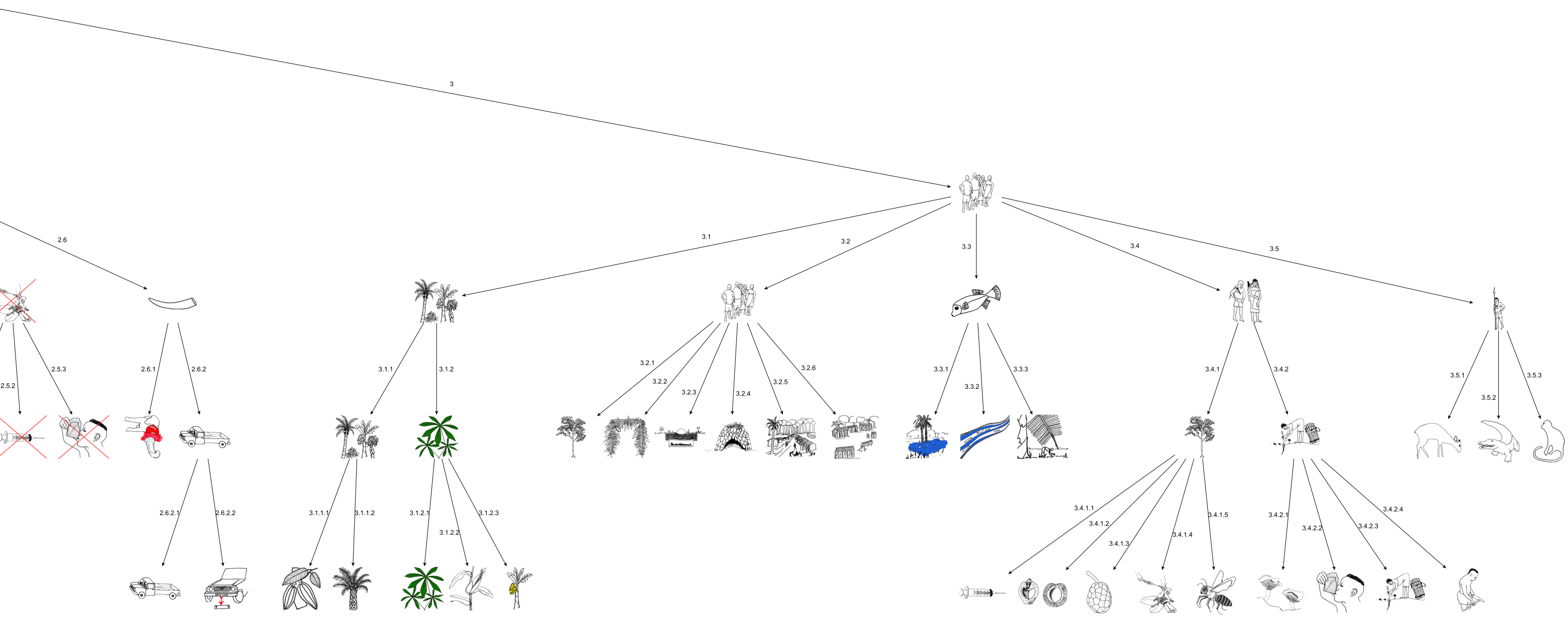
```
      <input ref="/TransportationExampleODK/pressed_walking">
        <label>Walking</label>
      </input>
      <input ref="/TransportationExampleODK/pressed_bus">
        <label>Bus</label>
      </input>
      <input ref="/TransportationExampleODK/pressed_tram">
        <label>Tram</label>
      </input>
      <input ref="/TransportationExampleODK/pressed_subway">
        <label>Subway</label>
      </input>
      <input ref="/TransportationExampleODK/pressed_train">
        <label>Train</label>
      </input>
      <upload mediatype="image/*" ref="/TransportationExampleODK/pressed_photo">
        <label>Photo</label>
        <hint>Photo</hint>
      </upload>
    </h:body>
  </h:html>
```

H IM-FLEG Decision Tree

Flip to the next pages to view the first (see page 344) and the final version (see page 346) of the IM-FLEG decision trees. If you are reading this document on a computer screen, make sure that your pdf viewer is set to Book View (or the equivalent option of your program) to see the next both pages into one screen.

IM-FLEG Version: 1.0

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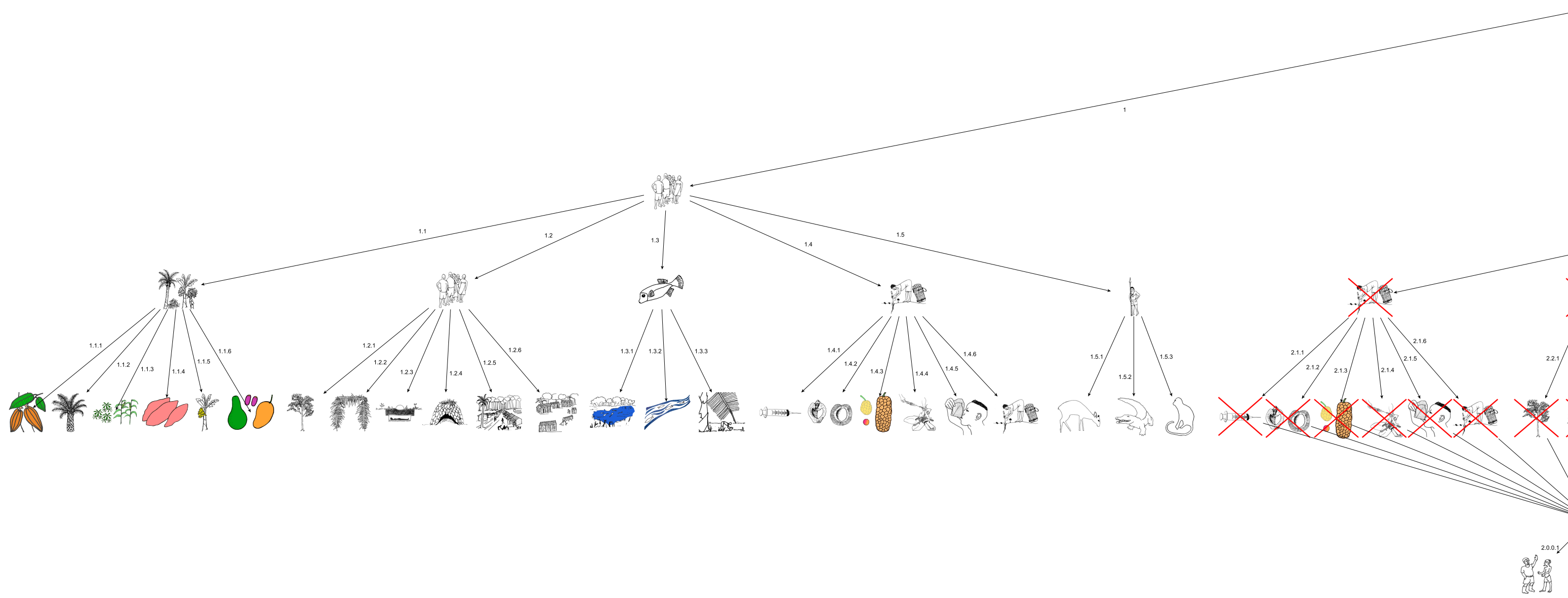
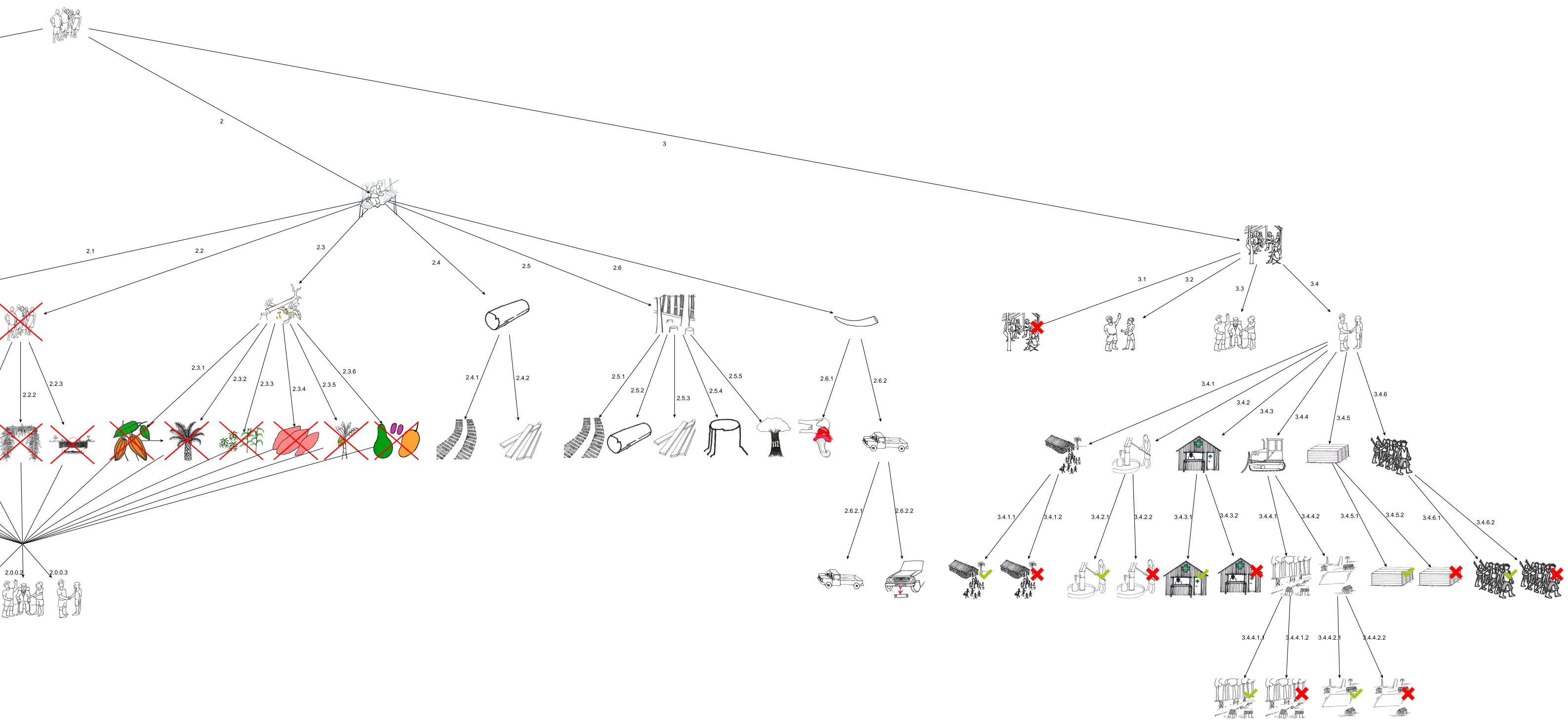
IM-FLEG Version: 1.4.4

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Case study 3: Participatory monitoring of logging: Technical work

I

I.1 Requirements

Table I.1.: Functional requirements for Sapelli platform

Req. #	Priority	Description	Rationale
General			
FR-G-10	High	Recurring from table F.5: The SMS transmission mechanism should ensure the safe delivery of records.	Due to network inconsistencies it was vital to ensure that SMS messages were delivered safely. Thus there is a need for a mechanism to detect network inconsistencies, acknowledge received messages and request retransmission of missing packages.
FR-G-11	High	Recurring from table F.5: The system should enable transmission of media attachments.	The effort to integrate Sapelli with the Dropbox Sync API proved unsuitable for the local network circumstances. Thus the system should be equipped with other mechanisms to upload media attachments.
FR-G-12	High	The system should support textual forms, containing widgets like checkboxes, text fields, and so on. The system should allow pictorial and textual forms to be harmoniously integrated with clear boundaries and possibly access restrictions between them.	This would be useful in cases where users with different abilities or roles needed to access the same device as indicated by FPP.

Req. #	Priority	Description	Rationale
FR-G-13	High	The system should allow the creation of mesh networks for data security and redundancy.	The reliance on the *Sapelli Relay* introduced a single point of failure that could compromise the transmission. Instead, a mesh network could improve data redundancy.
FR-G-14	High	The underline db4o database should be replaced with a more reliable database.	Although db4o allowed fast development due to the object-oriented nature, it caused stability issues on the platform. Hence a more reliable database was required.
FR-G-15	Medium	The system should allow data transmission to a GeoKey server for data storage and manipulation.	GeoKey was a server-side infrastructure to receive, store and disseminate geographic data developed by ExCiteS. This could replace the rudimentary *Sapelli Server* and provide stakeholders with more advanced tools to manipulate and disseminate the collected data.
Usability			
FR-U-12	High	Recurring from table F.5: The system shall explore alternative UIs to facilitate participants' navigation on hierarchical structures.	Participants were observed to have difficulties navigating on hierarchical structures such as the decision tree offered by Sapelli. UIs should be explored to assist participants understand the structure or offer them alternative modes for capturing data.

I.2 Sapelli development

The interaction with the communities allowed the development team of Sapelli to experience first-hand the technological and social challenges faced, and redefine the requirements as described in the previous section. This led to a development cycle to solve technological challenges, improve the stability and efficiency of the platform and extend it with necessary features on the one hand, but also led to an effort to explore alternative user interaction modes to solve the identified usability issues.

As noted, the core Sapelli was developed as a joint effort between Dr Matthias Stevens, Julia Altenbuchner and myself. As the platform progressed, each researcher/developer focused on different questions. However, the core Sapelli components had to undergo a series of improvements to enhance the platform's efficiency and stability. This was vital in order for the platform to be usable and attract collaborations with NGOs and local partners. Hence, the technical team had to plan, discuss, design, debug and test a series of improvements on the core of the Sapelli platform. The most important of these features are listed in table I.2.

In parallel to the core development, each person focused on different research aspects of the platform. As table I.2 shows, my main contribution on the second version of the platform was situated in the endeavour to improve the usability of the *Sapelli Collector* by introducing audio feedback and animated screen transitions as explained in section 8.3.

Table I.2.: Sapelli v2: Features contribution.

General improvements	
• SMS transmission: acknowledgement mechanism	Matthias Stevens
• SMS transmission: heartbeat mechanism	Matthias Stevens
• Deprecation of *Relay* and integration to Sapelli	Matthias Stevens & Michalis Vitos
• Improvements on the data export and data backup	Matthias Stevens & Michalis Vitos
• Integration with GeoKey	Matthias Stevens
• Addition of textual form elements	All
• Deprecation of db4o database and replacement with SQLite database	Matthias Stevens
• Redesign of management UI	Julia Altenbuchner
Usability improvements	
• Audio feedback	Michalis Vitos
• Animated screen transitions	Michalis Vitos
• Log user interactions	Michalis Vitos

Note. All refers to the *Sapelli technical team* of Julia Altenbuchner, Matthias Stevens and Michalis Vitos.

One of the most significant technological challenges identified in the field was the unreliability of the cellular network and especially the SMS delivery report system. As a result, Sapelli v2 was equipped with an improved SMS transmission that included mechanisms for acknowledging the delivery of an individual SMS message; the option for the receiver to request again the transmission of a single SMS message in case it was not delivered; and the concept of '*heartbeat*' SMS messages. A heartbeat was an SMS text sent by transmitters in the field, in predefined time intervals, to let the receiver know that the device is active and running. We envisioned that these changes could improve the reliability of the transmission system and solve the operator issues we identified and meet requirement FR-G-10.

Another issue we identified, was the extensive reliance on the *Sapelli Relay* for data transmission from the field to a cloud database (see figure 7.2, on page 125). This introduced a single point of failure that could compromise the data transfer. Instead, we merged *Sapelli Collector* and *Sapelli Relay* into one application (figure I.1). In this manner, when a project was set, the project manager could enter the telephone number of any other *Sapelli Collector* instance as the receiver; thus allowing any *Sapelli Collector* instance, either in the field or at the office, to act as an SMS relay and data aggregator. This could allow the creation of mesh networks and introduce multiple data instances, for security and data redundancy (FR-G-13). Multiple devices, for example, could be configured to send their data to different receivers. Another advantage of this implementation was the option to setup a local Sapelli instance as the data aggregator and in-situ export or visualise the data, offering instant feedback to the participants after a participatory mapping session. For instance, as Julia Altenbuchner's focus was on visualising and feeding back the data to local populations, this extension would be ideal for her testing in the field, where multiple Sapelli instances could send the collected points to a tablet running again *Sapelli Collector*. However, it is out of the scope of this thesis to further discuss this process.

Another improvement on Sapelli v2, was the ability to locally export data into CSV, or XML format (figure I.1) on the device's SD card and back up the Sapelli database and projects. While in the field, this functionality would enable the visualisation of the exported data on Google Earth (or any other GIS software) to provide participants with feedback or to edit the collected data on the one hand, and enable quick and easy debugging of the system for the technical team on the other.

In 2013, ExCiteS hired Oliver Roick to develop a new, web-based and open-source platform for participatory mapping, named GeoKey[1]. GeoKey is a server-side only infrastructure to receive, store and disseminate geographic data collected by citizens

[1]http://geokey.org.uk

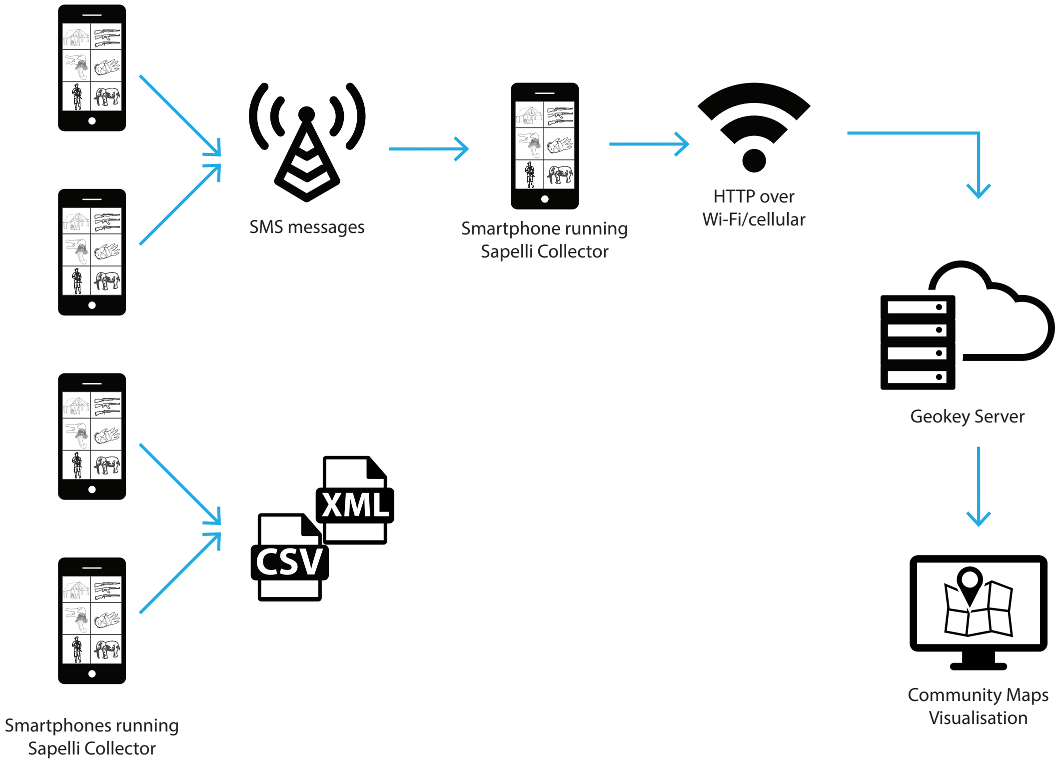


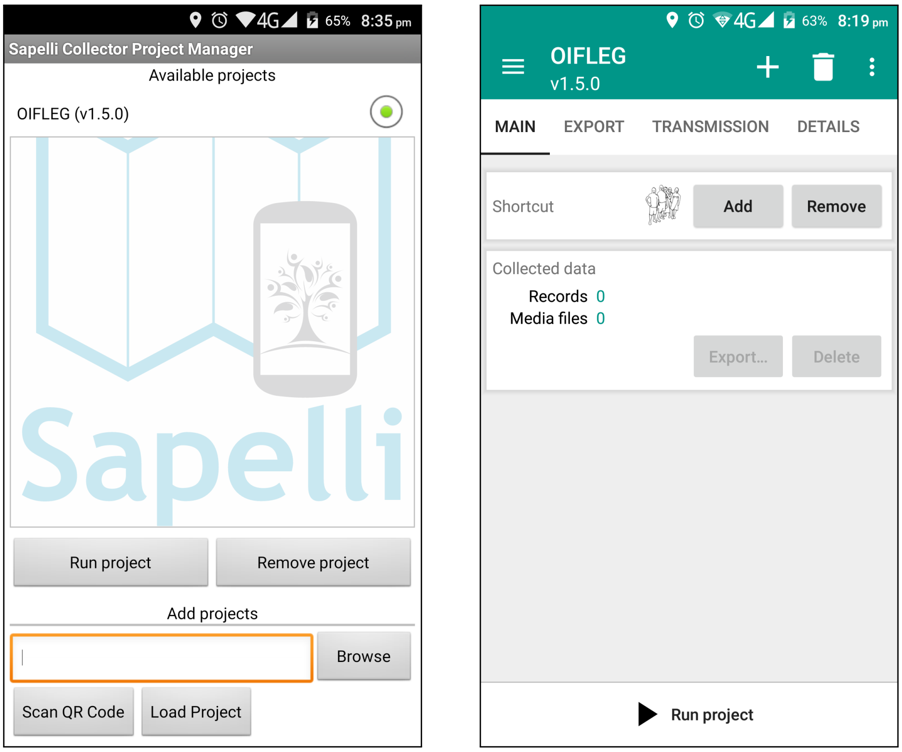
Figure I.1.: Sapelli v2 Platform Architecture.

via an open web API, and acts as the connecting point between data collection on the one hand and data utilisation through analysis and visualisation on the other. GeoKey also provides UIs to set up and manage projects, their data structures and users. In 2015, when GeoKey has matured, Matthias Stevens undertook the task of integrating Sapelli with GeoKey, which would allow Sapelli data to be stored in GeoKey (FR-G-11 and FR-G-15), and later permit the use of *Community Maps*[2] to visualise the data (figure I.1). Community Maps is a web-based visualisation platform developed by *Mapping for Change*[3], to disseminate and visualise data stored in GeoKey.

Again in 2013, ExCiteS has also collaborated with the international NGO FPP[4], to expand the UIs of Sapelli with textual forms, containing widgets like checkboxes, text fields, and so on. In this manner, Sapelli v2 could allow pictorial and textual forms to be harmoniously integrated with clear boundaries and possibly access restrictions between them (FR-G-12). As a result of integrating textual and pictorial interfaces, we also improved the SMS and HTTP transmission mechanisms allowing the sending of textual forms as well as the pictorial grid choices.

[2]https://communitymaps.org.uk
[3]http://mappingforchange.org.uk
[4]http://www.forestpeoples.org

As noted in appendix F.3.2, Sapelli v1 relied on db4o, an object database for internally storing data. However, in early 2014, the company that actively developed and maintained db4o announced their intention to stop supporting it (Versant Corp., 2014). Although the product was still open source and available, as Android evolved, many incompatibilities were introduced and the database caused stability and performance issues to Sapelli. At ExCiteS we did not have the manpower to maintain db4o; hence, in Sapelli v2, Matthias Stevens replaced the db4o-based storage layer with a new storage model based on *SQLite*[5], a SQL database engine supported by Android (FR-G-14).



(a) Sapelli v1: Management UI **(b)** Sapelli v2: Management UI

Figure I.2.: Project Management UI

Finally, the project management UI of Sapelli was heavily transformed on v2 of the platform. The project management interface offers project administrators a list of installed data collection projects as well as the means to add or remove projects to the list (figure I.2). Administrators could load projects either from the devices' SD card or the internet by entering the project URL or scanning a project QR code. However, Sapelli v1 had an antiquated and not very user friendly interface, which Julia Altenbuchner took over to redesign and modernise it, to comply with the Android guidelines. The new interface offered easier access to export options, transmission settings and details about the project (figure I.2b).

[5]https://www.sqlite.org

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Colophon

This thesis was typeset with $\LaTeX\,2_\varepsilon$. The style is based on Ricardo Langner's *Clean Thesis*, adapted to comply with UCL's guidelines and personal preferences. The following fonts were used: *Helvetica*, *Bookman*, *TEX Gyre Heros* and *Latin Modern Sans Serif*.
In term of tools, *TeXStudio* was used as the main Latex editor and *JabRef* as the bibliography manager. The bibliography back-end is relying on a combination of *Biblatex* and *Biber*, while the referencing follows the Harvard style.